REPORT

ON THE

HOOGHLY RIVER AND ITS HEAD-WATERS.

Vol. I.

CALCUTTA:

THE BENGAL SECRETARIAT BOOK DEPÔT

1919.

[*Price—Indian, Rs. 6; English, 9s.*]

REPORT

ON THE

HOOGHLY RIVER AND ITS HEAD-WATERS.

Introduction.

Origin of the Committee.—The present Committee was constituted by the Government of Bengal[1] with the object—

(*a*) of advising Government upon the steps necessary to ensure systematic observations of changes in the Nadia rivers,

(*b*) of suggesting what action was required to improve their condition as navigable channels and as feeders for the lower Hooghly

The Nadia rivers referred to are the three spill channels of the river Ganges, known as the Bhagirathi, Jalangi (or Bhairab-Jalangi) and Matabhanga (or Matabhanga-Churni), which after their junction form the upper waters of the Hooghly river They are clearly shown on a large scale in map No 2, volume II of this report The Bhagirathi flowing as it does in the abandoned channel of the Ganges itself is the oldest and most permanent of the three rivers It is the most westerly of the Ganges spill channels and relies for its main supply of water on the parent river. though the supply is supplemented to some extent by the rivers which drain the hilly country on the west side of its course The Bhagirathi after traversing the district of Murshidabad is joined by the Jalangi near Nadia, the headquarters of the Nadia district The Matabhanga, the most easterly of the three channels, swings round to the west and joins the combined Bhagirathi-Jalangi further south near a place called Chakdaha

Although the condition of the three feeder rivers had formed the subject of occasional enquiry and comment during the past century, it is doubtful whether its direct and important bearing on the efficiency of the main waterway leading from the sea to the Calcutta Port was sufficiently or generally appreciated until quite recent times It was not until 1902 that the need of an investigation into the state of the river for the length of 87 miles from Calcutta to the confluence of the Bhagirathi and Jalangi at Nadia came officially before the Port Commissioners In that year the Deputy Conservator of the Port made two important proposals—

Firstly, that a survey should be made of the upper reaches of the Hooghly

Secondly, that the limits of the Port of Calcutta should be extended to Naihati in order that the Commissioners might exercise jurisdiction as Conservators of the Port up to that limit and prevent the commission of acts likely to affect the waterway injuriously

The importance of the proposed extension was due to the fact that this section of the river was not under the special charge of any department or recognised authority, and that the rapid extension of mills and factories on the river banks in this area was resulting in the erection of structures projecting into the river, and reclamation of land from the Hooghly without any consideration of the general effect on the action of the river It was recognised at that time that such constriction of the waterway must interfere with the free tidal flow—a factor which, as will be shown, is indispensable for the conservation of the channels in a tidal river

2. **Proposals of the Port Commissioners in 1902.**—A preliminary enquiry disclosed the fact that with the exception of a rough survey made

[1] *Vide communique*, dated the 17th February 1917

in 1875 as far as Barrackpur and a regular survey of the whole river made between 1881—1885 by the Survey of India in conjunction with the Hooghly River Survey Department, no previous records of the state of the bed of this portion of the Hooghly river existed. In the latter survey no soundings had been made beyond Chandernagore, from which place to Nadia no records were in existence. In December 1902 the Port Commissioners accepted the proposals of the Deputy Conservator. In 1903 the Government of Bengal approved of the proposed survey, agreeing to pay one-third of the cost, but postponed a decision on the proposal to extend the limits of the port to Naihati until the completion of the survey on the grounds that it required careful consideration both from a legal and administrative point of view.

3 **The survey of 1909-11.**—Owing to the special surveys of the Hooghly river below Calcutta then in progress, no immediate action was taken for the survey of the upper reaches In 1906 on the representation of certain firms owning mills on the river banks, the Port Commissioners again urged the extension of the port limits The Government of Bengal, however, declined to take action on the grounds that the case for extension was based on too general grounds and that the conservancy of the river channel could be effected under the provisions of the Bengal Canals Act (II of 1864), the completion of the proposed survey was still awaited The survey was finally commenced on a scale of 6″ to the mile in 1909 and by 1911 had been carried as far as Bansberia, owing to the rapidly fluctuating character of the river bed above this point and the consequent difficulty of maintaining permanent triangulated points, essential for subsequent comparison on the river bank, it was decided for the time not to proceed with the survey between Bansberia and Nadia

4 **Recommendations of the Committee of 1913-14.**—In 1913-14 the Committee appointed to enquire into the existing facilities and present and future requirements of the Port of Calcutta dealt with the question of the condition of the upper Hooghly[1], they urged that steps should be taken—

(*a*) to ascertain the sources and volume of head-water passing through the port from the feeder rivers, Bhagirathi, Jalangi and Matabhanga, the direct tributaries from the high country in the right bank, and the amount due to drainage and percolation, etc ,

(*b*) to determine what action would be necessary to ensure the maintenance of a sufficient supply of head and fresh water ,

(*c*) to complete the survey of the river as far as Nadia and to revise the survey every five years , and

(*d*) to ascertain by observation the conditions obtaining in the feeder rivers at regular periods, including the extent to which their beds were rising.

5. **Inception of the present enquiry.**—On the basis of these recommendations, the Chairman of the Port Commissioners the Hon'ble Mr C J Stevenson-Moore, formulated definite proposals for the consideration of Government , he urged—

(*a*) that the first stage of the enquiry should consist of a scientific examination of the historical and hydrographical data available in the reports of Committees and expert officers regarding the Hooghly river and its head-waters, all information to be collected and collated,

(*b*) that the second stage should be the appointment of a Committee to examine the report on the first stage, to determine what conclusions could be drawn from it, and to formulate proposals for the systematic record and examination of such data as would indicate any improvement or deterioration in the head-waters of the Hooghly and any change in the channels of the feeder rivers or other rivers likely to affect the supply of fresh water

---

[1] *Vide* sections 139 and 140 of the Committee's Report

He further suggested that the first stage of the enquiry should be carried out by Major Hirst, I.A., Director of Surveys, Bengal and Assam. These recommendations were accepted by Government. A temporary subdivision of the Nadia Rivers Division (the Bhagirathi Observatory sub-station) with headquarters at Berhampur was formed for the purpose of taking observations of the discharge of water in the Bhagirathi, Jalangi, Matabhanga and Hooghly at fixed intervals. On 6th November 1914[1], Major Hirst commenced the first stage of the enquiry which was completed at the end of April 1915, his report being published in June 1916. In October 1916 the Government of Bengal issued a Resolution[2] on Major Hirst's report, and proceeded to the second stage of the enquiry by the constitution of the present Committee.

6. **Nature of the Report.**—The Committee's report completes the second stage of the enquiry. It has not been possible to keep strictly within the terms of reference. Major Hirst's report covered very wide ground. In dealing with the effect of a diminished fresh water-supply upon Calcutta as a port and the possibility of increasing it Major Hirst found it necessary to consider the problems of and advance certain theories regarding the general system of deltaic rivers in Bengal; he divided his examination under three main heads—

(a) the general formation of the delta and its rivers;—

(b) the major disturbing agents in the river system of Bengal; and

(c) the general effect upon the Hooghly of minor physical and local disturbances.

The conclusions arrived at by Major Hirst were of so alarming a nature that the Committee felt it impossible either to accept or reject them without the closest and most complete technical examination. These conclusions rested on the geological, geographical and hydraulic phenomena of the delta. The geological aspects of the problem were referred to Mr. H. H. Hayden, C.I.E., and Mr. E. H. Pascoe of the Geological Survey. Their report is printed in Appendix I and their conclusions have been freely referred to and summarised in the body of the report.

For reviewing in detail the more general geographical and hydraulic aspects of the problem the Committee obtained, with the permission of the Port Commissioners, the services of Mr. H. G. Reaks, River Surveyor, who has an intimate knowledge gained from long practical experience of the *regime* of the Hooghly river, and has made a special study of the factors which govern it. Mr. Reaks' valuable report which is reproduced as Appendix II, contains a general description of the deltaic river system, and brings together practically all the available historical and hydraulic data regarding the rivers with which we are concerned. His review has enabled the Committee to place their conclusions before Government in a concise form, and with the confidence that these conclusions are based on as complete and accurate information as it is possible to obtain. In printing Mr. Reaks' review *in extenso* the Committee also considered that the information contained therein would be of great value for purposes of reference in the event of the necessity arising in the future of undertaking extensive training or engineering works in connection with the control or improvement of the waters of the Hooghly.

The questions involved in the observation and collection of accurate hydraulic data were referred to a Sub-Committee[3] which reported on them under the following heads:—

1. Survey.
2. Land levels.

[1] *Vide* Notification No. 1360T.—R., dated the 2nd November 1914.

[2] Resolution No. 373-T.—R., dated the 9th October 1916.

[3] The Sub-Committee consisted of the President (the Hon'ble Mr. C. J. Stevenson-Moore), Col. Ryder, Mr. Cowley, Mr. Addams-Williams, Commander Constable, Mr. S. C. Williams and Mr. James Roy; it held four meetings and made two local inspections of the mouth of the Bhagirathi river and of the Hooghly river between Naihati and Howrah.

3 Hydraulic observations —

(a) tidal river levels,
(b) direction and velocity of tidal streams,
(c) discharges.
(d) percolation,
(e) composition of beds, shoals and sediment observation,
(f) surface slopes,
(g) limits of spill, and
(h) effect of Gangetic canals on spill channels

The report of the Sub-Committee is reproduced in Appendix III, and its conclusions are embodied in the report

The thanks of the Committee are due to Mr F D Ascoli, I C S, Secretary to the Board of Revenue, who has assisted them with the draft of their report

General Observations.

7. **Major Hirst's theory.**—Major Hirst arrived at the conclusions that the present regimen of the Hooghly is wholly insecure, that the forces controlling it are so powerful that any artificial interference would be futile, and that the river has deteriorated to such an extent as to be a menace to the Port of Calcutta If Major Hirst's conclusions were correct the position would be one of extreme gravity The volume of the head-waters of the Hooghly is according to Major Hirst's theory, primarily dependent on the geological processes which govern the delta as a whole He suggests that the Indo-Gangetic plain as far as Hardwar was once covered by the sea and that the land surface of Bengal has been gradually built up by river action At some recent period certain subsidences have occurred of which the most important follows a line from Jalpaiguri to the sea along the line of the Jamuna river, in compensation for these subsidences certain tracts have become elevated, such as the tract north of Dacca known as the Madhupur jungle These earth movements resulting in a series of elevations and depressions dominate the river action of the delta and are at present in a state of activity, and to such action he ascribes recent important river changes such as the changes in the courses of the Tista and Brahmaputra in the eighteenth century If these forces are still of such importance and activity as is assumed by Major Hirst, it must be conceded that human agency could be of little avail in attempting to improve the head-waters of the river Hooghly This theory is not, however, in accordance with geological opinion

8 **Major Hirst's theories untenable.—(a) Age of the Gangetic plain.**—Mr Hayden and Mr Pascoe's criticism of Major Hirst's views on the geological aspect of the problem is reproduced *in extenso* in Appendix I, but as our recommendations are dependent largely on the fact that the geological experts consulted are unable to ascribe the present condition of the head-water rivers to recent tectonic activity it is important that their conclusions should be explained here in some detail Messrs Hayden and Pascoe regard the behaviour of the Gangetic rivers as in no way different from that which characterises the normal processes of deltaic river development, they do not consider that the effects observed within the last few hundred years can reasonably be attributed to those slow crustal processes which act through geological periods, these processes, they assert, may be disregarded in any present enquiry in connection with the rivers of Bengal It is true that certain seismic phenomena may affect local river development, but the effects in the area involved in this enquiry are likely to be local and superficial rather than deep-seated and to have chiefly comparatively unimportant results, such as, the formation of fissures and the collapse of river banks It is not likely that the effects of regional movements could be detected in such a short period as three or four hundred years. It is pointed out that Major Hirst has not brought forward evidence in support of his assumption of the former submergence of Bengal beneath the sea, and Messrs Hayden and Pascoe prefer to adhere to the generally accepted view

that the Gangetic plain has lain above sea-level at least since an early date in the Tertiary epoch, and that there has been slow but gradual subsidence permitting of the accumulation of an enormous thickness of alluvial deposits, but they consider that regional movement of this nature, even if now operative, is not sufficiently rapid to justify its introduction as a factor in the present case

9 (*b*) **The old alluvium and subsidences.**—Major Hirst advanced or rather reaffirmed the theory advanced by Fergusson in the case of the Madhupur jungle that the exposure of the older alluvium[1] in certain places above the level of the surface of the younger deposits of the delta is due to a recent and gradual, though irregular, movement of elevation—the result of tectonic processes which have consequentially affected the condition of the deltaic rivers Messrs Hayden and Pascoe are not prepared to accept Major Hirst's arguments, on the other hand, there is clear evidence that the old alluvium generally has been subject to a process of very gradual subsidence fossils of the Pleistocene period being found at depths of 80 to 100 feet below the present surface The suggestion of Mr T H D La Touche[2] that the Madhupur jungle tract is a relic of the old delta face of the Ganges is regarded as a more satisfactory explanation Nor can Messrs Hayden and Pascoe find any justification for Major Hirst's assumption of a continuous line of subsidence, from Jalpaiguri to Java *viâ* Barisal or for other special areas of assumed subsidence such as that near Nadia They arrive at the conclusion, which we do not hesitate to adopt, that there is no evidence to justify the assumption that the gradual processes of elevation and subsidence are the dominating factors in the river development of the delta

10 **Change of conditions due to natural causes.**—Messrs Hayden and Pascoe are of opinion that there is no justification for believing that the condition of the Hooghly will inevitably become worse than in the past and that no deduction can reasonably be based on the assumed effects, in the course of a few hundred years, of the operation of tectonic forces, whether regional or local The alterations in the courses and condition of the deltaic rivers are capable of a simpler, more reasonable and equally satisfactory explanation in the ordinary well-known processes of riverine and deltaic development, the uniformity of the changes that have occurred indicate clearly that the causes must have been normal and not connected with tectonic phenomena The view that the development of the deltaic rivers has followed normal lines is not confined to geologists Mr Addams-Williams, who has studied very closely and comprehensively the history of the deltaic rivers and has an expert and technical knowledge as an engineer of the special hydraulic problems which arise, has endorsed this view in a note which is printed as Appendix IV of this report We cannot, therefore, accept Major Hirst's conclusion that the forces controlling the action of the deltaic revers are so powerful as not to be amenable to interference by human agency, neither can we accept his statement that the characteristics of the Nadia rivers differ from those of any other deltaic rivers, there are many other rivers in this and other deltas which are of the same type

11 **Alleged deterioration of the feeder rivers of the Hooghly.**—Major Hirst further contended that there has been a grave deterioration in the condition of the feeder rivers of the river Hooghly. In Mr Reaks' report will be found a detailed account of the rivers constituting the head-waters of the Hooghly showing their past history and present condition It must be admitted that the paucity of material data and records renders the task of determining whether there has been any progressive deterioration in the Nadia rivers one of extreme difficulty The history given by Mr Reaks shows that the rivers pass through successive phases of deterioration and improvement, which tend to obscure the general tendency and are apt to be misleading The condition of a spill river appears to depend almost entirely on the position of its offtake relative to the main stream of the parent river, when

[1] The patches of old alluvion as identified by Major Hirst are shown in colour in map No 1
[2] "Geological Magazine," New Series, Decade V, Vol VII (1910)

the latter is close to the offtake the bars are reduced in height and *vice versâ*. Now there is the evidence of the traveller Tavernier that in 1666 the mouth of the Bhagirathi was dry; in Rennell's time 100 years later the mouth in the dry season was closed or contained less than 2 feet water, in 1796 it was reported as an exceptional fact that the Bhagirathi was open to traffic throughout the year, in March 1824 the mouth was again closed. Conditions during the past century have been similar. Between 1825 and 1834 the mouth of the Jalangi was kept open for small boat traffic throughout the year on five occasions, but thereafter till 1847 it was closed in the dry season Under abnormal conditions the Matabhanga remained open in 1795 and again from 1809—1818 and in 1821—22, otherwise it was not navigable in the dry season till 1847. For the past 20 years none of these three rivers has remained open for traffic throughout the year on a single occasion, and the number and size of the shoals appear to be somewhat greater than in 1830. Conditions appear to have deteriorated to some extent probably due in some measure to the relative lowering of the low-water level of the Ganges on account of the abstraction of water by the Ganges canals Deterioration, probably of a temporary nature, has also taken place owing to the main channel of the Ganges having shifted from the right to the left bank opposite the offtake of the Bhagirathi. The process of deterioration, however, if indeed any permanent deterioration has taken place, appears to have been very gradual, and the fact that even with the evidence available it is difficult to arrive at a definite conclusion proves that the conditions cannot now be very materially worse than in the past The bed-levels of all the rivers constituting the head-waters of the river Hooghly appear to have risen very gradually in the past half century, though the rise seems to have been partially compensated for by a rise in the Ganges bed-level above Sara It will, therefore, be seen that the rivers pass through successive stages of deterioration and improvement, and that there is no definite proof that they have permanently deteriorated to any large extent

12 **Importance of maintaining the head-waters.**—Now it is important to realise that the state of the lower reaches of the river Hooghly is largely conditioned by the action of the tide wave, and that any restriction of the ebb and flow of the tide must result in the deterioration of the navigable channels of the river, the action of the tide is further supplemented by that of the freshets Mr Reaks in his report examines in detail the history of the Hooghly from Nadia to Calcutta and from Calcutta to the sea in order to prove the great importance of the freshets and of tidal action, and their mutual relations He shows that the exclusion of the Ganges freshets and reliance mainly on tidal action would gradually reduce the Hooghly to the same condition as such rivers as the Damodar and Rupnarayan, he further shows that any reduction of the tidal reservoir would react on the range of tide in the upper reaches Thus it is vitally important to extend tidal action as far up the river as possible so as to maintain the tidal reservoir and secure the resulting benefits of increased scour in the channels below. It is obvious that if the beds of the head-water rivers continue to rise more than those of the Ganges and the lower Hooghly, the result will be the obstruction of the freshets and the restriction of the action of the tide wave Any further deterioration of the head-waters would accordingly be a matter of extreme gravity, and it is imperative that steps should be taken to ensure a flow of water through the upper reaches sufficient to keep open the channels, but not such as to result in excessive deposits of silts of a heavier quality in the lower Hooghly The difficulties are clearly shown in Mr. Reaks' report, they may be summarised as follows —The canalisation of the three feeder rivers is almost impossible. To train the rivers by the *bandal* and spur system would not ensure a flow through the offtakes in the dry season The only alternative is dredging To dredge the whole of the channels of the head-waters would involve prohibitive expenditure, but it would probably suffice if powerful dredgers were employed at the offtakes to ensure a flow of water throughout the dry season which with the aid of *bandals* would keep open the lower channels. To ensure the success of such dredging operations it would be essential to improve the situation of the offtake of the Bhagirathi

13 **Danger of excessive interference.**—To improve the condition of the head-waters beyond this critical stage would not be advisable, and to improve them to the extent required for navigation by large boats throughout the year would be financially an impossible task. Quite apart from the increased deposits of silt which would necessarily occur in the lower Hooghly far more serious consequences might ensue It is clear that excessive interference with the bars at the offtakes of the spill rivers would result in the extraction of a large volume of water from the main stream of the Ganges and consequent shoaling below the offtakes in the dry season To make the Bhagirathi intake, for example, navigable for large boats and steamers throughout the year would necessitate a depth of about 9 feet of water in the entrance at the lowest stage of the river, to maintain such a depth by dredging, a channel 300 feet wide at least, and possibly as much as 500 feet, would be necessary to allow for the friability of the banks. Accepting the lesser width and allowing a longitudinal slope of 6″ per mile (a slope which statement K of Appendix II shows to be possible) the discharge through this channel would be approximately 8,000 cusecs, or one-fifth of the low water discharge of the Ganges. The extraction of such a volume of water must necessarily result in shoaling and possibly in preventing navigation between the offtake and Goalundo in the dry season. Indeed, it is not impossible that taking advantage of the depth of the offtakes at the beginning of the flood season the Ganges might revert to its old course, such a result, though the change would probably be neither certain nor sudden, would be calamitous But whatever might be the ultimate result it must be borne in mind that the maintenance of a depth of 9 feet water would necessitate the dredging of the head bar down to a level approximately 19 feet below the present bed, and that this would undoubtedly result in the influx of a far larger proportion of sand of greater coarseness than at present, and that such an influx must very seriously affect the tidal area of the Hooghly

14 **Obstruction due to reclamation.**—We have emphasised the vital importance of maintaining the conditions which secure the free and unobstructed flow of the tidal wave, but on the river banks north of Calcutta action has been permitted which tends to interfere seriously with this object We refer to the reclamations that have been made in connection with the erection of mills and factories between the Jubilee Bridge at Naihati, itself a doubtful factor in the regimen of the river, and Cossipur Such reclamations have been entirely uncontrolled Facing the Anglo-Indian Jute Mill, reclamation to the extent of 250 feet has been made since 1885 at a point where the river is only 1,400 feet broad, a spur and jetty at the Bengal Laxmi Cotton Mill has resulted in extensive accretions below that point, which have caused considerable deterioration in the river channel These are merely examples It must be recognised that the erection of mills and factories on the banks of the Hooghly is a necessary concomitant to the development of the Port of Calcutta, and it might further be urged that the reclamations and erection of masonry walls assist in stabilising the river and deepening the channel Such might be the effect in a non-tidal river, where an obstruction even if harmful would be local In a tidal river, however, the result may be widely different, the interference with the flow of the flood-tide reduces the force of the tide wave above the obstruction, the downward swing of the ebb tide is diminished and the area of the tidal reservoir is eventually reduced. These factors are of the utmost importance in the river Hooghly, which for eight months of the year depends upon the tide alone for keeping open its lower channels The necessity of controlling this area is accordingly apparent It is equally clear that the control should be vested in the hands of an agency which is in a position to examine the particularly difficult hydraulic problems involved.

Recommendations.

15. In view of the conditions summarised in this report we have formulated recommendations under three different main heads —

A.—The preparation and co-ordination of records for the investigation of the progress of deterioration in the river Hooghly and its feeders.

B.—Practical measures for the conservation and improvement of the feeders of the river Hooghly.

C.—Administiative control of the connected river system.

A.—Preparation and preservation of Records.

16. The importance of the Ganges freshets as an agency for maintaining he channels of the river Hooghly has been clearly shown in the report; to ensure the necessary spill through the Nadia rivers, on which the Hooghly is dependent for its existence as a deep-draft navigable river, it is essential that the physical conditions of the Nadia river system and the upper Hooghly should be accurately ascertained and reported It is true that Mr. Reaks' valuable report contains a mass of data, but these are not the result of the systematic and continuous observation which is essential for an accurate examination of the problems involved

17. **Co-ordination of records.**—We accordingly recommend firstly that all existing records, gauge level books, etc., should be carefully preserved, and that all data collected from time to time should be recorded in an easily accessible and intelligible form Thus the curves showing the annual observations, as recommended below, of gauge levels, dischages and mean silt contents should be plotted on the same sheet on a fairly large scale for each station, in order that any definite relation between them may be perceived Similarly the same series of curves should be plotted on a smaller scale from year to year to show continuous changes in levels, discharge and silt contents

We further recommend that the results of the proposed continuous surveys and observations and of the practical measures for the improvement of the feeder rivers should be recorded in a quinquennial review to be presented to Government by the Port Commissioners, this will ensure an examination at fixed intervals of the value of the measures now adopted and of the state of the feeder rivers.

18 **Surveys**—(*a*) **Large scale.**—The most important record on which all other observations should be based must be an accurate survey The latest general maps of the area are now more than 50 years old, and during this period considerable changes have occurred and the maps are accordingly obsolete. Recently, however, a survey of the river Ganges from Rajmahal to Faridpur has been made on a 16-inch scale in connection with the Faridpur and Rajshahi District Settlement Operations and Diara Surveys The cadastral surveys of Nadia and Murshidabad districts, which commenced in 1918, will by the year 1923 supply accurate maps on a 16-inch scale of the upper Hooghly, north of the Jubilee Bridge, the Bhagirathi. the Jalangi, the Matabhanga and the Churni rivers. Steps should be taken to obtain copies of these maps at the earliest possible date, for, though some delay is involved, they will form the most accurate basis for the detailed surveys required of the river beds. It is further important that steps should be taken to ensure the permanent demarcation of the traverse marks of these surveys in sufficient numbers to be of use for the revision of the maps and for the necessary large scale detailed river bed surveys

(*b*) **Small scale.**—In the course of their topographical programme the Survey of India have completed a survey on a scale of 1″=1 mile of that part of the Nadia district south of latitude 24° north covering the upper Hooghly and Bhagirathi as far north as Bhapta and the Jalangi as far north as Muktiapur, the maps are not yet complete and the area covered is not sufficiently extensive to form a good general map of the area. It will be necessary to await the reduction of 16-inch maps to the scale of 1″=1 mile to obtain a satisfactory general map.

(*c*) **Maintenance of maps.**—As changes in the river areas are rapid and extensive, in order to avoid the maps losing their value a small special staff should be employed for the revision of the maps of the Nadia rivers. The changes could quickly be shown on the small scale general maps, and where extensive changes were thus indicated, special large scale surveys would be made to keep the large scale maps up to date. Such a system would be more economical than constant surveys which would otherwise be necessary.

(*d*) **Special river bed surveys.**—The 16-inch maps would form the basis of river bed surveys which should be made on a uniform system, indicating—

Cross sections at distances of 300 feet, showing contours of shoals their size and shape.

Longitudinal sections plotted from the same datum.

As changes of considerable extent but often only temporary in character occur in river beds during the flood season, it is important that such river bed surveys should be made annually under similar conditions and at the same season, preferably at the end of the cold weather when changes are least active. In the tidal area of the upper Hooghly the river bed surveys should be undertaken by the staff of the Port Commissioners who have the necessary experience for this special form of work. These river bed surveys will be used, firstly, for the comparison of the annual longitudinal sections; and, secondly, for the calculation from the cross sections of the total capacity of selected 5-mile stretches of each river. Variations in capacity during a term of years will show whether the river is shrinking or not and will furnish a safer index than any comparison of individual cross sections. The result could be confirmed by the tendencies indicated in the low and high stage level curves.

(*e*) **Level Surveys.**[1]—It is of the utmost importance that scientifically accurate lines of levels should be taken in order to establish precise points of reference for levelling operations showing the general surface contours of the country. The following reference lines should be run by the Trigonometrical Survey as soon as possible —

(*i*) Ranaghat to Lalgolaghat *viâ* Berhampur, Murshidabad and Jiaganj.

(*ii*) Jiaganj to Ajimganj, thence by road to Rajmahal and Tinpahar to connect with line 74 of the present levels of precision.

(*iii*) Berhampur to present line 77 at Chuadanga *viâ* Meherpur.

(*iv*) Line 77 to Godagari *viâ* Rampur-Boalia and thence to Manihari opposite Sahibganj revising the crossing of the Ganges at Saraghat.

Lines of levels are at present being run over a portion of the area by the Public Works Department in connection with sanitary drainage projects. These should be related to the precise lines of levels described above and should be completed over the whole of the districts of Nadia and Murshidabad and extended to the Burdwan district as far as the Burdwan-Mangalkote Road on the west and the old bed of the Damodar river (Kana Nadi) on the south. Contour maps based on the general 1 inch maps should then be prepared, which in conjunction with the river bed surveys would furnish invaluable information regarding the relation of river courses to the level of the country through which they flow and would indicate the probability or possibility of any serious changes occurring in the course of the rivers.

(*f*) **Maps of spill areas.**—In connection with the level or contour survey maps should be prepared by Government showing the spill areas of the rivers in the area under consideration.[2] Such maps are essential for the preparation and examination of railway, road, drainage and embankment projects by railway companies, the Public Works Department and District Boards, as they will furnish a true indication of the extent to which the free action of rivers is likely to be restricted.

19. **Record of discharge—(*a*) Method of record.**—There are two main methods by which the volume of discharge is observed, one by Kutter's

---

[1] The fixing of a common datum for levelling operations is essential. Originally the Public Works Department adopted Kidderpur Old Dock Sill presumed in 1865 to be 6·25 feet below mean sea-level at Karachi, in 1883 its level was fixed at 7·986 feet below mean sea-level at False Point, finally corrected to 7·759 feet in 1910. All river surveys in the Hooghly made by the Port Commissioners have been referred to the Kidderpur Old Dock Sill Level as zero, and it is desirable that this should be retained as the basis of reference. Its value has now been fixed with reference to mean sea-level, and accordingly a common correction will reduce all levels to mean sea-level, the datum of the great Trigonometrical Survey of India; this latter datum is impracticable for purposes of navigation on the Hooghly as low-tide levels fall considerably below the datum.

[2] Such spill area maps would be invaluable throughout Bengal.

slope formula, the other by floats. Comparative results by the two systems show very wide differences, the former method showing invariably the greater discharge, at times 100 per cent. in excess of the float method. As the co-efficient of roughness (n) used for Kutter's formula was originally derived from a comparison with the discharges observed by the float method, it is clear that either the observations are faulty or a varying value of n is required for different states of the river.

Float method.—It is probable that under this method the co-efficient for the reduction of surface to mean velocity, viz., ·8 is too low. Experiments made by means of current meters on the Irrawaddy river resulted in a mean co-efficient varying between ·91 and ·93; the Ngawan and Panhlaing river experiments resulted in mean co-efficients of ·90 and ·97, respectively. It is important that a correct co-efficient should be determined. The calculation of the discharge in the final compartment of each series next to the river bank similarly requires greater accuracy.

Kutter's formula.—This method was condemned in the Irrawaddy river experiments on the ground that calculations of discharge by means of the slope formula could not be of any practical value on account of the continual variation of the water-level. This condemnation is probably too sweeping, but it must be remembered, first, that a general co-efficient of roughness in all states of the river is unsafe, secondly, that the position of the gauges requires very careful consideration, the total fall between two gauges being less than 2 inches it is essential that they should be placed in straight stretches in order to avoid defective observations due to want of parallelism, thirdly, that the gauges must be graduated with great accuracy to small units of measure, and, fourthly, that the gauges should be protected from the effect of the current at water-level, where the exposure of the gauge and the strength of the surface current must vitiate the observations. Those four points do not at present receive adequate attention. It would be advantageous for experimental purposes to erect masonry structures for gauges at suitable sites similar to those employed for this purpose in the Punjab canals. Enclosed chambers constructed of bamboo mats might also be experimented with.

The most accurate method of determining discharges, however, is by the use of a current meter, such as the successful Ritchie-Haskell type, by means of which the mean velocity in the whole vertical section can be obtained. Experiments with such meters should be made at least in the endeavour to obtain the necessary co-efficients required for use in the Nadia rivers with the float method and Kutter's formula.

(*b*) **Observation Stations.**—Stations for observing discharge should be organised at the following places:—

Bhagirathi river.—(1) In the Faracca channel above the Bhagirathi intake. (2) In the Faracca channel below the Bhagirathi intake. (3) Geria (4) Bansloi river above its outfall into the Bhagirathi. (5) Berhampur (6) Jumjumkhali. (7) Babla river above its outfall into the Bhagirathi (8) Dattabati (9) Ajai river above its outfall into the Bhagirathi (10) Katwa

Jalangi river at Panditpur

Matabhanga river at Hanskhali

Upper Hooghly river at Satgachi

Hooghly river at Calcutta

Damodar river
Rupnarayan river } at their junction with the Hooghly

Discharges in the tidal area are difficult to obtain with accuracy, but the Port Commissioners might arrange to have such observations taken at intervals. In the head-water areas, however, the observations must be carried out in a systematic and scientific manner with a properly trained and equipped staff. Rather than risk their accuracy by restricting expenditure on the proposed 12 head-water stations, it would be preferable to reduce the number of stations to five, viz.:—

Bhagirathi river at Geria and Katwa—the differences between these two stations would give the total supply from all the western tributaries.

Jalangi river at Panditpur.

Matabhanga-Churni river at Dewanganj and Hanskhali—the difference would give the discharge passing through the Kumar and Ichhamati rivers

The discharges measured and interpolated should be computed daily and the total quantities of spill from the Ganges entering each river during the year should be calculated to show any consistent increase or diminution of the supply. Full particulars should be furnished to the Port Commissioners to enable any direct connection between the height and quantity of the freshets and the condition of the channels in the lower Hooghly to be established

20 **Silt observation.**—Very little information of a definite value is at present available with reference to the important question of the silt contents of the rivers under consideration. It is essential that silt observation stations should be established as soon as possible for the purpose—

(*a*) of taking daily observations, at the surface, mid-depth and 1 foot above the bottom on a uniform system ,

(*b*) of ascertaining by exact methods the character of the suspended material and the proportion of silt to water by weight and volume and the velocity of the current ;

(*c*) of recording the observations made on a scientific system. The character of the river bed at the time of observation should be noted, and the composition of the bed at various places should be carefully ascertained, if necessary, by borings at important places and where important shoals occur

It is recommended that the observation stations should be located at Katwa, Swarupganj, and Hanskhali under the charge of the Public Works Department and at Calcutta under the charge of the Port Commissioners

21 **Tide observations.**—Changes in the rate of travel of the tidal-wave and of increase or diminution of the tidal range indicate, as has been shown, the measure of improvement or deterioration of the river channels It is accordingly recommended that observation stations should be located under the charge of the Port Commissioners in the upper reaches of the Hooghly at Konnagar, Palta, Gauripur, Dumardaha, Balagarh, Kalna and Swarupganj and on the Rupnarayan, Damodar and Haldi rivers, the Rupnarayan being the most important of the three rivers last named. The gauges should be read at half-hour intervals during the day, and high and low-water levels with the time of the change of the direction of the flow of the current should be recorded day and night Tide lines of selected typical tides should be plotted for comparison with similar tides in other years Steps should further be taken to ascertain definitely the limit of rise and fall due to tidal action in the Bhagirathi, Jalangi and Churni rivers

It is essential that the staff employed on the survey and observation of these rivers should be properly equipped both as regards instruments and means of locomotion

B.—Practical measures for the conservation and improvement of the head-water of the river Hooghly.

22 It has been shown in the report that indications of a certain measure of deterioration in the Nadia rivers do exist, and it is accordingly necessary that immediate steps should be taken for the conservation of the present fresh water-supply and for effecting such improvements which under present conditions appear likely to be not only beneficial but necessary for the future interests of the Port of Calcutta , at the same time it is necessary to avoid measures which would result in a heavier quality of silt being carried into the Hooghly and which might conceivably induce the main channel of the Ganges to follow this route. The stabilisation of the offtakes and the provision of sluices at the entrances to the spill rivers have been shewn to be not only financially impracticable but also very doubtful in execution. We have accordingly to make the following recommendations :—

23 **Dredging.**—A powerful dredging plant should be obtained to keep open one of the entrances, preferably that of the Bhagirathi, and the question

of providing a better intake channel than at present should be considered. The work of dredging should be done under proper supervision and on an approved general principle.

24. **Bandalling.**—The lower portions of the rivers should be trained as at present by bandalling according to the methods which have been evolved by years of experience, and which, if properly executed, are apparently capable of bringing about the desired results.

25. **Embankments.**—The erection of embankments without regard to the natural spill areas of rivers such as was permitted along the Bhagirathi river in the past may be fraught with very serious consequences. It is necessary therefore that for the future measures should be adopted which will ensure that the control exercised by Government shall be not only effective but directed towards a due protection of all the interests involved. The embankments which may cause obstruction to drainage can be classified as follows :—

(*a*) Embankments controlled by the Irrigation Department
(*b*) Private Zamindari embankments
(*c*) Roads maintained by the District Boards
(*d*) Railway Embankments.

In the case of embankments controlled by the Irrigation Department no action seems to be required as that department can be trusted to give due consideration to the problems involved As regards private zamindari embankments, the area should be notified under section 76 (*b*) of the Embankment Act to prevent the construction or alteration of any embankments without the sanction of the Irrigation Department

The construction of new District Board roads now requires the sanction of the Superintending Engineer of the Circle in his capacity as Inspector of Local works, but such projects, if of any importance, should be referred for the approval of the Irrigation Department

The chief danger, however, lies in the embankments of newly projected railway lines An important example of such a project is the cross connection which is proposed between the East Indian Railway, the Murshidabad branch of the Eastern Bengal Railway and the main Eastern Bengal Railway line at Bhairamara The proposed line will cross the whole drainage area of the Nadia feeder rivers at right angles to the general line of drainage. The crossings over the Bhagirathi, Bhairab and Matabhanga rivers have been selected at points where the banks are fairly stable, allowance has been made for the assumed maximum discharges of these rivers and water-ways have been provided for the maximum quantities of spill The Chief Engineer by whom a Railway Company's proposals in these respects must be examined and approved under the existing procedure can be relied on to see that the proposals, so far as technical details are concerned, are free from objection, but other interests may be involved to which he is not in a position to attach the importance which they may demand A project such as that which has been mentioned might exercise a serious influence on the efficiency of the Calcutta Port and its approaches Restriction of the free flow of water over the land may affect injuriously agriculture and the public health In view of these considerations, we are of opinion, that such schemes should be referred to a Board constituted on the lines suggested in the last paragraph of this report on which all interests likely to be affected would be represented before the schemes are completed and submitted for the sanction of Government. We consider that after a scheme has been sanctioned and completed permission to open the line should be withheld until an officer of the Irrigation Department has examined it and certified that water-ways have been provided in accordance with the orders of Government. We consider further that all works which fall under any one of the 4 classes above enumerated should be carefully examined before they are sanctioned with reference to complete and accurate contour and spill area maps.

26. **Effect of Gangetic Canals.**—The upper Ganges canals abstract from the river during the dry season at least 20 per cent. of the total discharge of the Ganges, and the lowering of the level at the time when the

maintenance of a high level is necessary for any spill to enter the Nadia rivers accounts to some extent for the frequent drying up of the entrances in recent years. It is impossible now to remedy the damage caused by completed irrigation projects, but it is essential that before any new schemes of irrigation or of increased supply to existing canals are sanctioned, the effect of the reduction of supply on the discharge of the Ganges below the canals should be considered with the greatest care and we recommend that sanction should not be given to such schemes by the Government of India until all the local Governments whose interests may be affected directly or indirectly have been consulted

C.—Administrative control of the connected river system.

27 **The head-water rivers.**—It is contemplated that the non-tidal head-water rivers will remain in charge of the Public Works Department, *i.e*, as far south as Nadia In the tidal area south of Nadia the Port Commissioners should be charged with the duty of surveying the river bed, their expert knowledge being required for observations of tide and discharge within the tidal area But in this area, survey is not the only necessity, stress has been laid on the importance of ensuring the free passage of the tidal wave and of the extension as far north as possible of the flow of the flood-tide, and it is accordingly essential that some responsible authority should be constituted to control the area either from Nadia or from the Jubilee Bridge southwards to Cossipur, the present northern limit of the Port of Calcutta, and thus prevent further encroachments on the river The area of the greatest importance lies between Cossipur and the Jubilee Bridge, and in this area it is important that control should lie with the Port Commissioners, as however the sphere of their activities must extend to Nadia for the purpose of survey and observation of tide, silt and discharge, it might perhaps be preferable to adopt Nadia as the limit of the Port Commissioners' control The extent and method of such control are, however, matters of some difficulty From the opening paragraphs of this report, it will be seen that proposals have previously been made for the extension of the limits of the Port of Calcutta as far as Naihati; we have carefully considered this proposal, but are not prepared to recommend it; for it would impose on the Port Commissioners over an extensive area duties and responsibilities which they do not desire, and for which they are not altogether qualified Our Committee has further considered the possibility of relying on the Embankment Act (Bengal Act II of 1882) or the Canal Act (Bengal Act V of 1864), these Acts would not however confer the necessary power of control on the Port Commissioners, and would not accordingly remove the present difficulties After mature consideration we consider that the simplest and most efficacious remedy would be the issue of a revised notification under section 4 (*1*)(*a*) of the Indian Ports Act (XV of 1908) The existing notification issued on the 2nd March 1897 conferred on the Port Commissioners the powers of Conservators of the navigable river channels leading to the port, south of the southern limits of the port at Budge-Budge; we now propose that a revised notification should be issued conferring similar powers on the Port Commissioners north of Cossipur as far as the Jubilee Bridge or perhaps to Nadia. It would then be possible for the Port Commissioners to issue general notices requiring that plans for the erection of new structures on the river banks in this area should be submitted to them for approval. It is true that the Port Commissioners could not compel compliance with such orders; but experience in the area south of Budge-Budge has shown that in the case of new erections the sanction of the Port Commissioners is ordinarily taken, and there is nothing to suggest that experience north of the port will be different. We are further of opinion that the power to enforce the provisions of sections 10 to 12, 21 and 30 of the Indian Ports Act will be of the greatest benefit to the port. Should the extension of the notification prove to be ineffective, we recommend the amendment of the Act to enable the Port Commissioners as Conservators of the channels leading to the port to control the erection of any structure below high-water mark.

28. **Control of general river system.**—It is hoped that this report has brought out with sufficient clearness the undoubted fact that the hydraulic problems which bear on the condition of the feeder rivers of the Hooghly are by no means entirely local in character. It has been shown that a study of the river systems of the whole delta is necessary for a proper understanding of the matter, that road, railway and drainage embankments in Central Bengal are important factors which directly influence the efficient action of these rivers, while yet further afield the construction of canals in Upper India, which draw water from the Ganges, is detrimental to the spill channels which supply the head-waters so essential to the conservation of the water-ways of the Calcutta Port The problem involved in the reduction by means of canals up country of the water discharged by the Ganges for the service of the Calcutta Port is analogous on a large scale to that which is explained in paragraph 13 as likely to arise at Goalundo and other centres of river commercial transport if the offtakes from the Ganges of the Nadia spill channels were so improved as to drain off a considerable portion of the water which now flows past them We venture to think, therefore, that in view of the far-reaching effects which may result, no new or enlarged canal scheme, which will draw its supply from the upper waters of the Ganges, should be sanctioned by the Government of India until the Provincial Governments of Bengal and Bihar and Orissa have been consulted Considering further the vital importance of the conservation of the deltaic rivers in the interests of drainage, irrigation, sanitation and transport and the risk of deterioration to which they are exposed in the event of undue restriction of their spill areas, we are of opinion that a Board should be constituted by the Government of Bengal to examine all important projects which are likely to restrict the free flow of flood-water and report to Government before such projects are sanctioned We suggest that the members of this Board should ordinarily consist of the Chief Engineer, Irrigation Department, representatives of the Sanitary and Agricultural Departments, of commercial interests and of Inland River Transport A representative of the Company responsible for the scheme under consideration should also be a member as well as a representative of the Port Commissioners when the scheme is likely to affect the area drained by the feeder rivers of the Hooghly The constitution of a Board on the lines recommended would ensure that no project is undertaken until the views of persons qualified to speak on behalf of all interests concerned have been duly considered

C. J. STEVENSON-MOORE, *President*

C H D RYDER

MANINDRA CHANDRA NANDI

RESHEE CASE LAW

H H HAYDEN

J CAMPBELL

A. R. MURRAY

C ADDAMS-WILLIAMS

E A CONSTABLE

(Messrs S C Williams and J E Roy have not signed the report owing to absence from India).

APPENDICES.

REPORT ON THE HEAD WATERS OF THE RIVER HOOGHLY.

APPENDIX I.

*NOTE ON THE GEOLOGICAL ASPECT OF THE CHANGES THAT HAVE TAKEN PLACE IN THE RIVERS OF BENGAL.

Chapters I to VII of Major Hirst's Report.

We have been asked to deal with the first seven chapters of Major Hirst's report which are concerned largely with what may be termed "The geological aspect of the changes that have taken place in the rivers of Bengal." Major Hirst has gone into these changes in great detail, and has concluded that they are due in the main to crustal movements, resulting in the elevation of some, and the depression of other, parts of Bengal and Assam After careful study of his arguments, we are not convinced that his deductions are justified or that the effects referred to are necessarily attributable to the causes that he postulates All the features of the Gangetic delta (in this term we include the combined delta of the Ganges and the Brahmaputra) seem to us to be normal, and to be such as might be expected to occur in any large deltaic area, and the features referred to by Major Hirst in Chapter VII as "marked abnormalities" would not be described by us by that term. Thus Major Hirst refers (page 21) to the winding nature of the channels of the Nadia rivers as an abnormality. This feature is one which is essentially characteristic of all rivers flowing through flat country, and will be found described in most text-books, the following quotation from one of which (Geikie Text-book of Geology, Volume I, page 499) will suffice "One of the most characteristic features of streams, whether large or small, is the tendency to wind in serpentine curves when the angle of declivity is low, and the general surface of the country tolerably level This peculiarity may be observed in every stream which traverses a flat level plain" The causes of this are fairly obvious and well known and need not be quoted here A glance at any one of the maps of the deltaic areas of Bengal will show that this feature is a prominent one in the case of all the Bengal rivers It is further a matter of common observation, as well as a natural deduction, that rivers flowing through comparatively flat country are readily affected by comparatively small obstacles—a fact which was evidently in Major Hirst's mind when he wrote on page 36, paragraph 2(?) "It seems to be quite possible that considerable change is caused to the river bed through sunken boats and perhaps here and there through snags" Sunken boats and snags are not the only obstacles that might affect the course of a deltaic river, thus local rainfall may induce heavy floods in comparatively small feeders of a large river, and this and other seemingly insignificant causes may be sufficient to produce apparently incommensurate results. The fact that the main channel of the Ganges has changed from the Hooghly to the Padma is not, in our opinion, a "peculiar" phenomenon [page 12, paragraph 4 (*f*)], but is only what might be expected in a deltaic area In this connection we may quote again from Geikie's text-book of Geology, page 515 "When a river enters upon the delta portion of its course, it assumes a new character In the previous parts of its journey it is augmented by tributaries, but now it begins to split up into branches, which wind to and fro through the flat alluvial land, often coalescing and thus enclosing insular spaces of all dimensions. The feeble current, no longer able to bear along all its weight of sediment, allows much of it to sink to the bottom and to gather over the tracts which are from time to time submerged Hence many of the channels are choked up, while others are opened out in the plain, to be in turn abandoned, and thus the river restlessly shifts its channels * * * * The typical delta of the Nile affords an excellent illustration of the main features of delta-building. Of the seven ancient mouths of this river only two now remain" Indeed, the history of most deltas is similar to that of the Ganges.

2. To sum up, therefore, we see no reason to regard the behaviour of the Gangetic rivers as other than such as characterises the normal processes of river development, and we do not consider that the effects observed within the last few hundred years can reasonably be attributed to those slow and gradual crustal processes, included under the term *diastrophism*, which act through geological periods.

3. We are not convinced, therefore, that those gradual changes, implied by the terms *elevation* and *subsidence* as employed by Major Hirst, can be regarded as operative from

* Received with Director's letter No 1764, dated the 31st July 1917

the practical point of view, and we consider that they may be disregarded in any present enquiry in connection with the rivers of Bengal. At the same time, there are undoubtedly certain tectonic phenomena which probably have effects, more often indirect, on the general trend of development of the rivers of the Bengal-Assam system. These tectonic phenomena are, as a rule, comparatively deep-seated, and their effects on the surface are, as we have just remarked, usually only indirect. They take place suddenly and violently, and are generally accompanied by vibrations of greater or less intensity. When violent, they are noticeable as earthquakes. Although it occasionally occurs that an earthquake is accompanied by visible changes of level at the surface, this is exceptional, and in broad alluvial areas like Bengal, the more noticeable effects are purely superficial, and result in the formation of fissures and sand-vents and in the collapse of river-banks. It is true that in the great earthquake of 1897 distinct faulting was observed in the Garo Hills (Geological Survey of India, Memoir, XXIX), but no evidence could be found of its extension into the plains. At the same time, the bed of the Brahmaputra appears to have been appreciably affected at certain points and was distinctly raised, though, whether this was due to actual uplifting of the bed itself or to an unusually rapid rate of deposition of silt, attributable to merely superficial causes, it was found impossible to determine

4. On the whole, therefore, the only effects of crustal movement which, we consider, can be fairly accredited with any effect likely to be appreciable within the next few hundred years on the rivers of Bengal are the sudden and more or less violent superficial disturbances due to earthquake tremors, and we are not convinced that the gradual movements of subsidence and elevation postulated in Chapter IV by Major Hirst are real. Apart from the fact that such movements usually take place so slowly that they are not likely to be appreciable within such short periods as three or four hundred years, the arguments deduced by Major Hirst in favour of their existence do not appear to us to be entirely convincing

5 In expressing the above opinion, we feel that it is necessary, at the risk of being tedious, to deal with Major Hirst's arguments in some detail The first point to which we need draw attention will be found in the last paragraph of section 2 on page 7, in which Major Hirst states that Bengal was once covered by the sea, and that from the Himalaya to the sea there is somewhere below the surface a flat plinth upon which the whole delta lies. This paragraph involves assumptions of great importance, and, as they conflict with the views generally held regarding the geological history of the Gangetic plain, it is necessary to examine them in some detail Throughout the whole of the Gangetic plain, from west to east along its northern margin, there is no trace of any marine deposit formed along the foot of the Himalaya That an arm of the sea covered parts of Assam in Cretaceous and in early Tertiary times is proved by the presence of marine fossils in the Khasi and Garo Hills, that that arm may have extended across the site of the present Indo-Gangetic plain in pre-Tertiary and possibly even in Eocene times, *i e*, before the existence of the Himalaya as a great mountain range, is conceivable, but the absence of Tertiary marine deposits, and the presence of Tertiary fresh-water deposits, throughout the Outer Himalaya from Dehra Dun to Sikkim, show that, since the elevation of the Himalaya, marine conditions have not existed in that area, nor is there any evidence of the existence of such conditions at any point in the Gangetic plain between the Himalaya and the Peninsula. It is true that we know very little about the nature of the deposits underlying the Gangetic plain. For such knowledge as we have, we are dependant mainly on borings at Ambala, Agra, Lucknow, Chandernagore, Fort William and Canning The deepest of these borings reached a depth of only a little over 1,300 feet, but the boring at Agra pierced the alluvium completely without disclosing any beds of marine origin, nor were any such beds met with in any of the other bore-holes This matter has been dealt with at some length in the *Manual of the Geology of India*, 2nd edition (1893), and we need not reproduce the details here, we may merely point out that Major Hirst has adduced no evidence in favour of the contrary view that he now puts forward, and we do not consider that it would be safe to reject the generally accepted conclusion that the conditions prevailing over the Indo-Gangetic plain from comparatively early Tertiary times have been not dissimilar to those that exist at the present day, and that there has been a slow but gradual subsidence, permitting of the accumulation of an enormous thickness of alluvial deposits, whether such subsidence is still operative we are not in a position to say, but even if it is, we do not consider that its action would be sufficiently rapid to justify its introduction as a factor in our present deliberations

6 The next point to which we may draw attention is the reference in Chapter IV, paragraph 1, to a former land surface which is said to have subsided at some time, but subsequently to have been caused "to rise irregularly, and show its face above the level of the modern surface" Presumably this old land surface is what is termed, in geological literature, the older alluvium, which is found in most places at no great depth below the present surface That it has subsided is evident from the fact that it contains fossil remains of terrestrial mammals at depths of from 80 to 100 feet below the present surface. These fossils are of Pleistocene age, and the rate of subsidence that would be deduced therefore, assuming that it is not complicated by movements of elevation, would be extremely small Major Hirst appears to believe that this older alluvium has subsequently been raised irregularly, presumably by tectonic processes, and he points to certain areas in which the older alluvium is now to be seen above the present surface. In this he is following and amplifying the views expressed by Fergusson, and till recently accepted, with regard to the area known as the Madhupur jungle That the Madhupur jungle is an area of special elevation may or may not be true, but that there is also, throughout the

Gangetic plain, a large number of areas, which have been similarly elevated, requires more evidence than is here brought forward. The chief facts relied on appear to be—

(1) the presence of the older alluvium beneath the present surface at various point and at varying depths ;

(2) the presence of hanging valleys on the banks of the Lakhya river.

Neither of these phenomena seems to us to justify the assumption that irregular elevation has taken place. The fact of the older alluvium being an old land surface dating from the Pleistocene period would lead us to expect it, like the Pleistocene alluvium of the Narbada, to show a considerable amount of superficial irregularity. The older alluvium of the Madhupur jungle is from 60 to 100 feet above the surrounding country, but we do not consider that even a difference of level of 100 feet in an old land surface must necessarily be explained by special tectonic processes resulting in elevation. Although we are not prepared to deny that the Madhupur jungle may be, as Fergusson claimed, an area of special elevation, it seems preferable to regard it as a result of ordinary superficial processes, its more pronounced character being attributable to the simple and familiar causes assigned by Mr. LaTouche in his paper on the subject published in the Geological Magazine for 1910. That paper was apparently not accessible to Major Hirst, and a study of it may perhaps lead him to revise his conclusions.

7. The second phenomenon referred to by Major Hirst, viz, hanging stream-beds, though sometimes indicating that elevation has taken place, does not necessarily involve that process We are inclined to question the propriety of the use of the term in this connection and would suggest that the fact that the rate of erosion of the Lakhya river is apparently greater than that of some of its tributary streams may be due to other and simpler causes, several of which might be enumerated, but, without an examination of the ground, the assumption that they were operative would be no less hypothetical than Major Hirst's assumption of recent elevation We do not consider, however, that the mere existence of hanging stream-beds is, as stated in the report, "conclusive evidence of recent elevation"

8. The statement, made in the same connection, that in Jalpaiguri the outside limits of the old alluvium are "clearly broken by fractures," requires, in our opinion, elaboration and amplification. The conditions assigned to Jalpaiguri by Major Hirst seem to us contradictory, for, in one paragraph (paragraph 3, page 10) he refers to this area as furnishing evidence of recent elevation, whereas in the next he postulates the presence of a line of subsidence running from Kinchinjunga through Jalpaiguri to the sea.

9 Other aspects of the question of the relationships of the older alluvium also seem to us to require further elucidation Major Hirst has prepared an interesting map (plate 5) showing what he regards as the distribution of the old and new alluvium in Bengal An accurate map of this kind would be of considerable academic interest, especially if it were on a large scale It is possibly due to the smallness of the present scale that considerable areas of Trap and Gondwana rocks in the Rajmahal Hills, and Tertiary rocks along the foot of the Himalaya, have been included in the older alluvium Detailed information as to the bedding of this old alluvium would also be of interest. Major Hirst states (page 10, paragraph 3) that it dips under the modern surface Possibly he was not using the term 'dip' in its technical sense, as indicating the effects of folding processes which result in the tilting of beds, once horizontal, till they are inclined to the horizon. Although false bedding and current-bedding may reasonably be expected to occur in the Pleistocene alluvium, we know of no recorded instances of true dip, and if Major Hirst's reference to the islands of old alluvium *dipping under* the modern surface is intended as evidence of folding, facts in support of the inference should be adduced. Mere undulation of the surface is, of course, no proof of tectonic action, and, in the case of a deposit so young as Pleistocene, would more probably be due to natural processes of denudation.

10. Turing now to the points enumerated by Major Hirst as furnishing "evidences of subsidence in Mid-Bengal," we do not find the grounds put forward convincing.

With regard to (*a*), paragraph 4, page 11, the fact that the line along which the supposed subsidence is assumed to have occurred would, if produced, meet a very highly elevated tract of the Himalaya, does not seem to us to offer any evidence of subsidence, whereas, even if we accept the statement (for which we doubt if there is any real evidence) that there has been *unusually heavy* faulting in the hills, it should be remembered that most of the faults of importance known to occur in the Sikkim Himalaya run approximately paralled to the Himalaya, and we know of no system of cross faulting of which a line of subsidence stretching from Jalpaiguri to the sea would be an element. The evidence based on Fergusson's deductions with regard to the alluvium of the Madhupur jungle is, even if accepted, of only local application, and, if, as we incline to think, LaTouche's views are found to embody a more rational explanation than Fergusson's, the evidence hitherto adduced in favour of the existence of a line of fracture in this part of the Brahmapurta valley disappears. That there may be many fractures under the alluvium is possible, but the cloak of alluvial deposits renders it

impossible for us to make any definite observations on the subject, and we do not feel that any of the grounds put forward by Major Hirst would justify the view that the existence of a continuous line of subsidence, such as he postulates, has been proved.

With regard to the evidence given under (*b*), even if we accept the hypothesis that the so-called "Barisal guns" are of seismic origin, the fact of the occurrence of such seismic phenomena at Jalpaiguri, at Barisal and in Java, does not, in our opinion, justify the assumption that a single line of subsidence connects either all or any two of these places.

The hypothesis referred to under (*c*) does not necessarily involve subsidence. An equally probable, and more usual, cause would be simple erosion.

The questions dealt with under (*d*) have been considered by Mr. LaTouche in the paper already referred to, and his views afford a very reasonable explanation, if one is required. It is not unusual, however, for one part of a delta to be in a less advanced state than other parts.

With regard to (*e*), abrupt changes of the character of the strata are not uncommon in alluvial areas.

The behaviour of the Damodar, and Major Hirst's statement that the general trend of the drainage has changed within comparatively recent times from south-east to south-west, seems to conflict with the evidence adduced under (*f*)

(*g*) refers to Fergusson's theory, with which we have already dealt

(*h*) is presumably intended not as evidence but merely as an inference.

11 On the whole, therefore, we do not feel that the case put forward by Major Hirst, either for recent elevation or for subsidence, is convincing, nor do we consider that either of these processes need be taken into consideration in connection with the human aspect of the question of the development of the rivers of Bengal

12 We have read with great interest the detailed information with regard to the history and the characteristics of individual rivers embodied in Chapters V to VIII, and, while realizing the amount of investigation that these chapters must have involved, we are not convinced that the characters of the rivers have been shown to be such as would justify their being regarded as abnormal They seem to us to be following the natural course of deltaic development and we see no reason for the assumption, recorded on page 23 (paragraph 5), that subsidence has taken place in the neighbourhood of Nadia In a flat country, such as the plains of Bengal, it may be expected that a water-channel will be affected by comparatively insignificant events, which may nevertheless be sufficient to give rise to changes of its course It seems to us to be an arguable proposition that the change of the main stream of the Ganges from the Hooghly to the Padma was effected with very little effort, for, if the allegory embodied in the first four paragraphs of Chapter VIII is to be given any historical weight, it would appear from paragraph 4 that, when Ganga followed Bhagirath, the difference in importance between the Hooghly and the Padma was so small that she mistook the one for the other. We do not, however, put any great faith in "evidence" of this type, and we merely quote it to show that it is open to more than one interpretation

13. There is, so far as we can see, no reason to assume that the present channel will necessarily be any more permanent than the Hooghly has been. Fergusson's arguments as to the ponding back of the Ganges in 1838 seem to us very convincing, but proof one way or the other is undoubtedly a matter of great difficulty, and the question is probably too complicated to offer reliable evidence as to any possible effect on rivers so far up-stream as the Hooghly.*

14 With regard to the question of the future of the rivers of the delta, restoration of the Bhagirathi, or of one or other of the streams flowing south to the Hooghly, might easily occur in consequence of a comparatively small alteration of conditions in the Ganges This may be exemplified with reference to the Bhagirathi The present spill-feeder (see sketch) takes off from a loop in the Ganges, which points towards the south-west, as is well known, loops tend to extend themselves, and to become more and more completely circular or elliptical As this happens, the centrifugal force of the water sweeping round them increases, and any spill-channel taking off from the *outside* bank of the loop should be augmented by reason of this centrifugal force. The loop of the Ganges from which the Bhagirathi at present takes off may be expected to extend to the south-west, and to invade slightly the Bhagirathi, thus increasing its curve The Bhagirathi may by that time have cut through its own loop, which at present gives it such a bad take-off, and may thus attain a more favourable take-off and derive reinforcement of its water therefrom, and also from the increased centrifugal current in the main river Both the Jalangi and Mathabhanga occupy rather similar positions The prospects of the Hooghly would thus appear favourable rather than unfavourable, but, of course, there is always the possibility of the spill-feeders completely changing the position of their points of take-off and taking off from the inside bank of a bend As we have already pointed out, however, small causes not infrequently have incommensurably large effects, and it is always possible that some small accident, such as a fall of bank or a slight shifting of the channel, due either to a flood or to excessive local deposition, may arrest the development sketched out above, it is, in our opinion impossible to foretell in what direction development will take place, and we regard as highly speculative, and of doubtful utility, any attempt to forecast the future on these lines. At the same time, we are not convinced that there is justification for

* But see also LaTouche, *Geological Magazine*, 1910, page 201

believing that the condition of the Hooghly will inevitably become worse than it has been in the past, and we certainly do not consider that any deductions can reasonably be based on the assumed effects, during a course of a few hundred years, of the operation of tectonic forces, whether regional or local.

H. H. HAYDEN,
Director, Geological Survey of India.

CALCUTTA,
The 31st July 1917.

E. H. PASCOE,
Superintendent, Geological Survey.

Extracts from the Geological Magazine, New Series, Decade V, Volume VII (1910).

Relics of the Great Ice Age in the Plains of Northern India by T. H. D. LaTouche, Geological Survey of India.

THROUGHOUT the valley of the Ganges and its tributaries patches of what is known as the "older alluvium" are to be found, rising to a considerable height, often as much as 100 feet, above the present flood-levels This alluvium is generally to be distinguished from the later river-silts by its red colour, which has given the name of Rangamati (coloured earth) to so many villages in Bengal and Assam, and by its containing quantities of the peculiar nodular form of limestone known as 'kunkur,' the presence of which is in itself a sign that the deposits are of considerable antiquity, for it owes its origin to the slow accretion of particles of carbonate of lime dissolved out of the slightly calcareous sediments by percolating water, and redeposited in the form of nodules as the water evaporates

One of the most conspicuous instances of this old alluvium is the elevated tract known as the Madhupur jungle, extending to the north of Dacca between the present channel of the Brahmaputra and its old course into the Meghna The soil of this tract is a stiff red clay, evidently an old river-silt, but raised to a height of some 60 to 100 feet above the flood-levels of the rivers on either side. Several other patches occur in the lower Ganges valley, but as we ascend the river and its tributaries into the United Provinces and Bundelkhand, we find that this older alluvium is almost universally distributed, and has a distinctive name, that of 'bhangar' in contrast with the low-lying 'khardar' or straths along the river-courses, and that it bears every sign of being in a state of rapid erosion, that it belongs in effect to a condition of things that has now passed away, when the rivers probably possessed a much greater volume of water and brought down correspondingly greater quantities of silt

* * * * * * * * *

It is always a source of satisfaction to the geologist, or indeed to any scientific man, when he finds that a theory intended to explain a certain series of facts can be used to clear up difficulties that may surround another series of equally well-ascertained facts. The changes of the courses of the rivers of Lower Bengal have for a long time exercised the minds of surveyors, engineers and geologists and various explanations of them have been put forward, especially of the comparatively sudden desertion by the Brahmaputra of its old channel, which ran to the east of Dacca at the beginning of the last century. This problem was first seriously attacked by Mr Fergusson fifty years ago, and partly turns on the question of the origin of the elevated tract of ground I have already mentioned, the Madhupur jungle. He attributed it to a special upheaval of that part of the delta which deflected the Brahmaputra into the Meghna and the jheels of Sylhet. But we should have to apply the same reasoning to other patches of the older alluvium, and it is difficult to suppose that each of them is due to a special upheaval, moreover, one would think that an upheaval in that particular place would be more likely to force the Brahmaputra westwards than deflect it to the east. Nor does it account for the fact that the Brahmaputra, now a much larger river than the Ganges, allowed itself to be pushed aside in this way, or that, considering that it brings down very much more silt than the Ganges, it should have done so little towards filling up the Sylhet jheels. But a study of the present river-courses will, I think, throw some further light on the subject

The Dihang, which, as is now universally admitted, brings down the waters of the Tsanpo of Tibet into the Brahmaputra, is not, I think, the original main channel of the latter, but was, until quite recent times, a mere tributary It is only within the last thirty years that it has been proved beyond doubt that the Tsanpo is connected with the Brahmaputra, though Rennell was the first to recognize that it must be so in 1765. Only a few days ago I saw a modern atlas in which the Tsanpo was shown as flowing on eastwards into the Salween. Now it is not at all unlikely that, at the period I have been speaking of, the Tsanpo either flowed westwards, as Burrard and Hayden maintain, and escaped through the Himalaya at some other point, or lost itself in the deserts of Tibet, and that then the Dihang was a mere tributary of the Brahmaputra, but that it has since cut back at its head into the valley of the Tsanpo and "beheaded" it. If this was so, the Brahmaputra must have been a comparatively small river at that time, and it is not

surprising that in its lower course it was pushed aside by the alluvium brought down by the Ganges and its tributaries. Indeed it may be that the Madhupur jungle is a relic of the old delta face of the Ganges, and that to the east of it, at that time, there was open water, reaching perhaps up to the foot of the Khasi Hills ; in this way I would account for the backward state of that part of the delta. But when the Dihang beheaded the Tsanpo, and brought down this enormous accession of water, the Brahmaputra began to assert itself. At first it could do little, for the accumulation of alluvium in its path was too great to be swept away, and it had to be content with its old course into the Meghna ; but it had a treacherous ally in the Teesta, which had gradually been sapping the defences of the Ganges. The Teesta, wandering from side to side over the old alluvium south of its exit from the hills, swept it away by degrees, wearing down the face of the country to the west of the Madhupur jungle, and in course of time opened a passage for the spill-water of the Brahmaputra down the Jennai river.

Finally the Teesta, frankly deserting its lawful sovereign, the Ganges, threw itself suddenly (this happened so recently as 1787) into the Brahmaputra. The effect of this was not at first noticeable, but it is probable that the extra silt brought down by the Teesta was too much for the Brahmaputra to deal with hampered as it was already by the damming back of its waters by the Meghna as the latter slowly raised the levels of Sylhet, and that the two allied rivers were compelled to find a new channel. The insignificant Jennai offered the means of escape and its bed was occupied about one hundred years ago.

The struggle that then began between the Brahmaputra and the Ganges is still in progress and issue was joined so recently, almost within the memory of men now living, that we cannot suppose that it has yet been fought to a finish, or that developments may not take place that will have far-reaching effects upon the future history of Bengal. The Brahmaputra, being the more powerful river, is not likely to rest content with the advantage it has already gained Up to the present time, indeed, it has not been able to exert its full strength, for it cannot do so until it has brought the level of the Assam valley to the state in which it would have been had the valley been originally excavated by river of the size and power of the present Brahmaputra. As it is, much of the force of the river when in flood is spent in the low ground flanking its course, but when this has been brought to the true 'regimen,' there is no doubt but that the river will be able to show its real strength with more effect in its lower course. Even in 1838 it had succeeded in damming back the Ganges to such an extent near the confluence that the latter was fordable at several places above Goalundo, and was compelled to seek for a new exit to the sea The Garai, which leaves the Ganges at Kushtia, was enlarged from a mere creek unable to float a vessel drawing more than a foot or two of water, as Rennell found it in 1764, to a broad and deep river, now the principal steamer-route from Calcutta to the Upper Ganges. What further developments may take place we cannot predict, but it is possible that their influence may be felt still higher up the Ganges, and may even extend to the Jalangi or the Bhagirathi, and so affect the welfare of Calcutta The mitigation of any evil effects these changes may have is a matter for the consideration of engineers If they become acute, something might be done to assist the Ganges by inducing the Tista to return to its old allegiance , but the forces exerted by such vast bodies of moving water are so prodigious that it is unsafe to speculate without a complete knowledge of the facts

APPENDIX II.

Report by Mr. H. G. Reaks, River Surveyor of the Port of Calcutta, on the physical and hydraulic characteristics of the rivers of the delta—

MAPS (*Vide* Vol. II.)

No 1 General Map of Bengal showing Deltaic River System

No 2. General Map of Nadia Rivers System

No 3 Map showing changes of Bhagirathi entrance

No 4 Upper Hooghly Nadia to Bansberia

No 5 Hooghly River Nadia to the Sea

No 6 Approaches to Hooghly Saugor to Sandheads, showing erosion of seaface and extensions of sands

No 7. Map showing changes of channels in Estuary of Hooghly

No 8 River Hooghly Map by Thomas Bowrey, 1687

No 9 Map of River Hooghly of probable date 1690 Section 1

No 9. Map of River Hooghly of probable date 1690 Section 2

No 10 River Hooghly Point Palmyras to Calcutta, probable date 1720

No 11 River Hooghly Map by Ritchie and Lacam of probable date 1735

No 12 River Hooghly Illustrating Leonard's and Brooks' projects for improving James and Mary

No 13 River Hooghly Illustrating Sir Charles Hartley's project for improving James and Mary

No. 14 River Hooghly Illustrating Vernon Harcourt's project for improving James and Mary

No 15 River Hooghly Illustrating Lindon Bates' project for improving James and Mary.

No. 16 River Hooghly Illustrating various projects for improving Moyapur and Royapur Crossings

No. 17 Map showing encroachments on river at Calcutta since 1793

PLATES (*Vide* Vol. II.)

No. 1. Curves of High and Low flood levels in Bhagirathi river

No 2. Curves of High and Low flood levels in Bhairab and Matabhanga-Churni rivers.

No 3 Longitudinal section at Bhagirathi entrance

No 4 Discharge curves of Bhagirathi river for 1916-1917

No. 5 Discharge curves of Jalangi and Matabhanga-Churni rivers, 1915—1917

No. 6 Discharge curves of Ganges and Hooghly

No 7 Monthly mean river level curves, 1881 to 1916, at Kidderpore, Calcutta Comparative Mean River level curves Curve of Mean Baric pressure, Bay of Bengal

No 8. Comparative curves of High and Low water at the four phases of the moon at Kidderpore

No 9 Comparative curves of Highest and Lowest, High and Low waters at Kidderpore

No. 10. Daily mean river level curves at Swarupganj, Palta, Kidderpore and Phuldobi on River Hooghly 1916-1917 Duration of flood and ebb periods at Calcutta

No 11 Tidal High and Low water lines on Hooghly

No 12 Simultaneous tidal lines on Hooghly Freshets and Dry season

No 13 Tidal curves, River Hooghly Freshets and Dry Season

No 14 Curves of cross sectional areas, River Hooghly

No. 15 Comparative curves of Hooghly river widths and Longitudinal Sections

No 16 Curves of available depths on Bars and Crossings in Upper Section of navigable Hooghly.

No. 17 Curves of available depths on Bars in Estuary of River Hooghly

No 18 Sections of strata at Calcutta shown by borings.

No. 19 Longitudinal Sections of River Hooghly

CHAPTER I.

General description of the Deltaic Rivers.

Gangetic delta

General description

THE Gangetic delta covers an area of about 25,300 square miles in Bengal, forming a rough triangle bounded by the Hooghly on the west, by the Meghna and Chittagong coast on the east and with its apex at the head of the Bhagirathi effluent between Rajmahal and Rampur Boalia.

Deltaic streams dependent on spill from Ganges or tidal action

Effect of interference with spill

2. The delta has been formed by the action of three great rivers, the Ganges, Brahmaputra and Meghna. It is intersected by innumerable rivers and creeks running generally in south, or south-easterly courses into tidal estuaries on the sea face. Some of these estuaries have a direct connection with the Ganges, while with others, such as the Bhairab, Nabaganga, Chitra,* Kobadak, Harihar and Bhadra rivers in the Jessore district west of the Madhumati, which formerly derived their supply through the Matabhanga, the connection from various causes partially, artificial, has in the course of time been severed and the rivers have become merely local drainage channels Other rivers originate in bils or marshes and rely on tidal spill. Where the spill, whether tidal or from the Ganges, has been interfered with, the streams are in process of degeneration

Watershed of Ganges and Brahmaputra

General description of Ganges

Bhagirathi effluent

Mahananda river

3 The Ganges and Brahmaputra, rivers of the most importance in considering the formation of the western portion of the delta, have their sources within a hundred miles or so of each other, but on opposite sides of the Himalayas, and bring down into Bengal the combined drainage from both slopes of that great watershed, including the discharge from the melting snows of the mountains. The Ganges after issuing at Hardwar from its source in the Himalayas, flows down past Allahabad, where it is joined by the Jumna It runs in a generally easterly direction along the southern side of its central valley, skirting the northern edge of peninsular India, and receiving successively as affluents on its left bank the rivers Gumti, Gogra and Gandak, draining the Himalayan southern slopes, and on its right bank the Tonge and the important Sone river. Just above Sahebganj, the Kosi joins it fromthe north and the Ganges then sharply rounding the outlying fringes of the Rajmahal hills, follows a general south-easterly course. Shortly after passing Rajmahal, it enters on its deltaic career, giving off its first effluent the Bhagirathi, at Geria, about 34 miles above Rampur Boalia. A few miles further down, the Ganges receives its last tributary, the Mahananda.

Bhairab Jalangi

Sialmari river

4 About 18 miles below the Bhagirathi entrance, the Bhairab spills southward over the right bank 11 miles above Akriganj and joins the Jalangi, the upper channel of which from the offtake of the Matabhanga, is now closed and only flows in the flood season A short distance below the Bhairab offtake, the Sialmari spills over during the rains and also runs into the Jalangi. The combined rivers flow south-westward and meet the Bhagirathi at Nadia to form the Hooghly.

Baral & Atrai rivers

Matabhanga off-shoots

Kumar and Ichhamati

After passing Rampur Boalia, the Baral river is thrown off from the left bank and this stream flowing through the Chalan Jhil and combining with the Atrai from near Jalpaiguri, joins the Brahmaputra above Goalundo. About 19 miles below Rampur Boalia and the same distance above Sara, the Matabhanga takes off from the Ganges at the old Jalangi entrance and, flowing in a south-westerly direction, enters the Hooghly near Chakdaha under the name of the Churni. Two offshoots are given off from the left bank of the Matabhanga the Kumar draining south-eastward into the Nabaganga and to the Sea by the Marjata estuary and the Ichhamati, flowing southwards, joining the old Jabuna and finally passing into the Raimangal estuary These two streams, the Kumar and Ichhamati, which Major Hirst believed to be practically closed (paragraph 4, Chapter VI of his report) have been estimated to take away at present about seven-tenths of the spill supply of the Matabhanga, only three-tenths of the discharge passing through the Churni into the Hooghly

Old Bhairab course.

Kobadak river

6 Between the Kumar and Ichhamati, the old Bhairab used formerly to continue its course south-eastward and into the Madhumati past Jessore, giving off the Kobadak river early in its career. The heads have silted up, and in its lower portion the Bhairab has been deflected to drain into the Pussur or Marjata estuary, but the Kobadak still flows into the Malancha as it did originally.

Nadia rivers

7. The three feeder rivers, Bhagirathi, Bhairab-Jalangi and Matabhanga form the system known as the Nadia rivers. Their spill offtakes from the Ganges are subject to great variations in position in the course of years and the condition of the rivers as regards the supply of water in the dry season is largely dependant on the favourable or unfavourable situations of these changing offtakes.

Garai Madhumati effluent

Ganges Brahmaputra confluence

Meghna river

8. The Ganges passes Sara 19 miles after throwing off the Matabhanga and above Kushtia, or about 12 miles below Sara, it gives off the Garai effluent, which lower down under the name of the Madhumati, flows into the Bay through the Baleswar and Haringhata estuary. The Ganges meets the Brahmaputra at Goalundo, about 59 miles below Sara Below Faridpur, the Padma, as the combined river is called, splits into branches and later at Chandpur, the Meghna flows into the main river, which debouches into the Bay of Bengal under that name.

---

* According to Hunter the Chitra river was artifically disconnected from the Nabaganga whence it formerly received its spill supply, by an embankment which an indigo planter threw across its head about 1830 According to the same authority the connection of the Kobadak with the Matabhanga was severed through the action of Mr Shakespeare, a former Magistrate of Nadia, who cut a channel across the neck of a bend of the Matabhanga at the Kobadak offtake

Physical characteristics of Ganges

9. The Ganges has a length of 1,540 miles and a catchment area of 397,500 square miles with an average rainfall of 42 inches. From February to May, its average discharge at Sara just below the Nadia offshoots is probably below 50,000 cusecs. This begins to increase in May and rises to an average maximum of 1,500,000 cusecs at the end of August, or the beginning of September. The greatest discharge ever measured was 1,926,080 cubic feet per second on the 22nd August 1910 and the probable maximum discharge at extreme high flood level would be 2,500,000 cusecs. The river level is consequently lowest in April and May. It begins to rise in the latter month and then more sharply early in June, attaining its maximum height about the end of August, there is usually a subsidiary freshet which maintains the flood level in the first half of September and it then falls gradually to its lowest stage, the flood being imperceptible by the end of November

Discharge Plate 6

Silt charge

10. From experiments at Rampur Boalia at the height of the flood season in August 1909, the Ganges was estimated to carry an average proportion of dry silt by weight of 1 to 473, or about 924 grains to the cubic foot. In September 1903 the proportion measured at Sara, was 1 to 527, or 830 grains to the cubic foot In August and September, the proportion is estimated at 1 to 760, or 575 grains, at the head of the Ganges canal. The sand found in the river at Sara is very fine, all passing through a sieve with 75 threads to the inch and only 58 per cent being stopped by a No. 100 sieve. From Sahebganj to Sara the average slope is 3·36 inches to the mile in the dry season and 3 inches to the mile in flood. At Goalundo, at the confluence of the Ganges and Brahmaputra, the fall is 4·15 inches in the dry season and 4·50 inches to the mile in the flood season. The slope of the river of course varies naturally at different points according to conditions and at Sara where conditions are abnormal, it was found, when the river was in high flood, to vary at points a short distance apart from as little as 3½ inches to the mile, to as much as 15 inches to the mile, changing at one point just below Sara, from 9 to 15 inches to the mile as the river rose from the low to its high stage.

Slope of the Ganges

Variation of slope

General description of Brahmaputra

11 The Brahmaputra is 1,800 miles in length and has a drainage area of 361,200 square miles over country with a heavy rainfall, the average in the Assam Valley being about 88 inches After traversing Tibet in an easterly course as the Tsan Po, it emerges into Assam under the name of Dihong and flows south-westward through an alluvial plain in the Assam Valley, 450 miles in length with an average breadth of 50 miles, receiving various tributaries on both banks, draining the Himalayan slopes on the north and northern slopes of the Assam hills from the south The Brahmaputra then curves round the western spurs of the Garo hills, where it receives the Tista on its right bank and under the name of Jamuna, flows due south to join the Ganges at Goalundo, receiving the Baral-Atrai combination on its right bank and throwing off the Dhaleswari distributary about 44 miles above Goalundo. This latter river, the upper portion of which has deteriorated, runs south eastward, splitting into two branches, one of which the Buri Ganga flows past Dacca and then combining again with the other branch enters the Meghna at Narayanganj An old silted-up course of the Brahmaputra branches off from the present main stream, opposite the old mouth of the Tista, and continuing the curve round the Garo hills spur, drains south-eastward past Mymensingh and into the Meghna

Tsan Po

Tista river

Dhaleswari and Buri Ganga

Old course of Brahmaputra

Slope of Brahmaputra

12 The slope of the Brahmaputra, which is 16 inches to the mile at Dibrugarh at the head of the Assam Valley, decreases to 6 inches at Tezpur in the middle of the valley, and then to 4¾ inches and 4½ inches at Dhubri where it commences to flow south. At Goalundo, where it joins the Ganges, the slope as mentioned before is 4⅛ to 4½ inches to the mile during the dry and flood seasons respectively.

Discharge

13. The low water discharge of the Brahmaputra is about 150,000 cusecs, no reliable figures are available for the flood discharge, which is probably greater than the Ganges The river level at Gauhati commences to rise in March and a small flood of about ten days' duration usually occurs at the beginning of May, owing to early rains. The river then rises steadily till the middle of July, remains at its highest level for two months, and then falls gradually from the middle of September to its lowest stage in the middle of February. The silt charge from experiments made at Gauhati was 1 to 3,260 by weight in April, increasing to 1 to 1,500 in July and is probably greater when the river is in full flood, in the Padma at Goalundo, the proportion by weight was 1 to 446 in August 1909. The sand here is very fine, practically all passing through a sieve with 90 threads to the inch

Silt charge

Variability of Ganges and Brahmaputra channels

14 From the foregoing description of the physical characteristics of these rivers, it will be seen that the Brahmaputra and Ganges are large rivers having a small fall as they enter the delta which is naturally further reduced in their progress to the sea. They carry a heavy charge of fine silt * and flowing through flat plains of easily erodible alluvial deposits of their own making, their courses are naturally subject to great alteration In the course of ages, the Ganges must have wandered over wide tracts seeking the sea and raising its delta gradually. The main stream must thus have occupied various positions in the course of time and, as suggested by Mr. La Touche, the elevated area of old red clay alluvium of the Madhupur jungle near Dacca may have been at one period the delta face of the Ganges

15. The available evidence as regards the early courses of the Ganges must be admitted to be generally indefinite and scanty But, judging by the condition of the delta which has on both its eastern and western margins, comparatively well raised and settled land with a depressed marshy region in the middle [Faridpur, Jessore districts],

* The Mississippi in flood is estimated to carry a proportion of silt by weight of 1 to 1,500 the Irrawaddy 1 to 1,840 the Nile 1 to 670 and the Indus 1 to 287

in continuation of which to seaward, lies that deep hollow at the head of the Bay of Bengal, known as the Swatch of No Ground, it seems improbable that a heavily silt laden main stream has ever debouched, or if ever, for any considerable period, through the middle of the delta.

Probable old course of Ganges

16. So far as can be ascertained from early traditions, the existence of old beds, and towns with old histories on the banks of the river, the main Ganges stream from the dawn of history in Bengal (which, however, must not be taken to be of very ancient date), flowed south down the course of the present Bhagirathi to about the vicinity of Tribeni, a name signifying the junction of three streams This was the most natural and direct course to the sea. At Tribeni* the Saraswati branched off south-westward, entering the present Hooghly at Sankrail and then according to Sherwill and Fergusson, flowed through Garden Reach and Tolly's Nullah (known as the Adi, or original Ganga) and past Baruipur into the Sattaramukhi and Channel Creek (or Buri Ganga) to Ganga Sagar. According to Sherwill, in 1857 a former branch of the Saraswati could be traced from Chanditolla past Amta into the Damodar and Rupnarayan and so through the lower Hooghly to the sea † The Jabuna branch of the old Ganges ran south-eastward from Tribeni somewhat along its present course The intermediate portions of the Hooghly from Tribeni to Tolly's Nullah and from Sankrail to Fulta (the latter according to Sherwill known as the Kata (or cut) Ganga, were probably at first smaller streams which enlarged later on as the main branches began to decay

Alternative suggestion drawn attention to by Mr Addams-Williams

17. An alternative and more probable suggestion is that at Tribeni the Ganges divided into three streams (1) the Saraswati flowing south-westward past Satgaon and emerging into the present Hooghly at Sankrail, with a main branch running past Amta into the Damodar and probably also the Rupnarayan and so into lower Hooghly, (2) the Jabuna following the direction south-eastward along the route of the decayed stream of that name, (3) a middle branch, which was the Bhagirathi proper, flowing south along the present Hooghly channel to Calcutta and then through Tolly's Nullah (the Adi Ganga) to the sea, before reaching which it split up into a number of branches, one running into the lower Hooghly at Diamond Harbour

18 In the Bengali poem 'Chandii' written by Kabikankan in A D 1577, Chand Sodagar's voyage to Singhal along the Bhagirathi, the present Hooghly, can be clearly traced by the mention of various existing villages, such as Tribeni, Khardah, Konnagar, Kutrang, Kalighat (now on the Adi Ganga) Baruipur and Magra

Artificial connection between Saraswati and Bhagirathi rivers through Garden Reach

Kata Ganga or Garden Reach

19 The Bhagirathi before that time is presumed to have run independently of the Saraswati, but a connection was at some period established by an artificial cut through Garden Reach and the river appropriated and enlarged the channel, till it became the main stream, as a consequence of which both Tolly's Nullah and the upper Saraswati decayed The term Kata (or cut) Ganga, as given by Sherwill to the Hooghly below Sankrail, appears to be a misnomer and really refers to that portion between Tolly's Nullah and Sankrail which is supposed to have been cut through. The tradition of this cut having taken place is still extant in some quarters and is supported by the fact that the Hooghly water in Garden Reach is not regarded as the traditionally sacred water of the Ganges

Condition of Hooghly at Sankrail

20. The present peculiar configuration of the Hooghly which widens considerably just below Sankrail at the old Saraswati entrance, affords additional confirmation The left bank here is concave and thus suggests a deep water channel having at some time run along it, which can be most naturally explained by its having been the continuation of the Saraswati channel from Sankrail, now maintained by the flood tide current. The present deep channel along the right bank is a continuation of the Hooghly channel which would have cut across the other at right angles, and they merge at the end of the reach in a deep hole where the cross sectional area is abnormal, being much greater (as will be seen on plate No. 14) than in any part between Calcutta and Fulta, in spite of the natural tendency of the river to enlarge in the lower reaches

Diversion of main Ganges channel, beginning of 16th century

Old Ganges course through Chalan Jhil

Junction of Padma and Meghna

21. The main Bhagirathi channel of the Ganges gradually deteriorated and presumably the branches which must have run to the eastward into the delta improved correspondingly, until it is surmised that about the beginning of the 16th century, the main stream definitely took a south-easterly direction It then probably followed the course defined by Rennell and Sherwill past Rampur Boalia through the Chalan Jhil, Dhaleswari and Buri Ganga rivers past Dacca into the Meghna In course of time the Ganges opened out other channels to the south until it reached its present course and in Rennell's time, before the Brahmaputra joined it, flowed through the Arialkhan river and its branches to the eastward, to the sea. Later, after the Brahmaputra joined it at Goalundo, the combined rivers broke eastward through a cross connecting stream shown by Rennell south of Rajabari, into the Meghna at Chandpur. There is evidence to show that this had occurred by 1794, but in 1840 according to James Taylor in his Topography of the Dacca district, the channel was 3 to 4 miles wide and had a very strong current which rendered navigation by small boats dangerous during the rains.

Gaur and Nadia capitals of Bengal

22. It is known that Gaur on the Upper Bhagirathi and Ganges near Malda, was the capital of Bengal from the 7th century, except for periods when for military or other reasons, the capital was transferred to other towns. When Gaur was temporarily

* Pliny, 116 A D & Ptolemy, 140 A D mention Tribeni Arrian A D 161 refers to Katadupa or Katwa (Sherwill)

† Rennell also refers to this course The Hooghly channel below Hooghly Point gives the appearance of being really a continuation of the Rupnarayan and was probably actually formed at a very early age by the main branch of the Ganges which is presumed at one time to have flowed past Tamluk The Hooghly above Hooghly Point would probably then have been either a smaller branch or a tributary

Satgaon the ancient port of Bengal on Saraswati river

abandoned at the end of the 12th century, the capital was moved to Nadia, which was lower down presumably on the main stream.

23 Satgaon situated on the Saraswati, was the ancient royal port of Bengal but when the earliest Portuguese adventurers came to India in 1518 and 1530, they landed at Chittagong, showing apparently that the main approach to the capital was from the eastern side of the delta, and this is partly confirmed by De Barros, who stated in 1540 "Satgaw (Satgaon) is a great and noble city though less frequented than Chittagong on account of the port not being so convenient for the entrance and departure of ships." Gaur was temporarily abandoned for Tanda closer to the Ganges in 1564 and later fell into decay. In 1604 Dacca became the capital.

Deteriorated state of Saraswati in 1565

24 Satgaon on the Saraswati was a flourishing city in the first quarter of the 16th century when the Portuguese visited it, but the river had been gradually decaying and in 1565, according to Cæsar Frederick, large ships did not go beyond Bator (Sibpur) "because that upwards the river is very shallow and little water, the small ships go to Satgaw and there lade" From this, it would appear that even then the lower portion of the Saraswati had decayed and the approach to Satgaon was along the Bhagirathi to Tribeni and then down the Saraswati about 4, miles The Portuguese established the Settlement of Hughli about 1575 on the present Hooghly channel and owing to its more easily accessible position, the town soon increased in importance at the expense of Satgaon and finally, after its capture by the Moghul forces from the Portuguese in 1632, it was adopted as the royal port and Satgaon fell into decay Calcutta was founded at Sutanuti in 1690.

Hughli established by Portuguese 1575.

25. From these facts,—the deteriorated condition of the Saraswati at the beginning of the 16th century and the absence of any traceable allusion at that date to any former large branches of the Ganges other than the modern Hooghly channel on this side,—the assumption seems to be justifiable that the main change of the Ganges course to the south-east, which had probably been some time in course of formation, was definitely effected by the end of the 15th century

26. After the great change in the course of the Brahmaputra channel during the latter half of the 18th century when it entered the Ganges at Jaffarganj near Goalundo, the latter river endeavoured to avoid the conflict by forcing a new passage to the sea through the middle of the delta As Fergusson points out, the Ganges was fordable at several places above the junction with the Brahmaputra in 1838 It was also fordable in 1857 according to Sherwill The Garai river which offered the most convenient passage, increased in width at its offtake, from 600 feet in 1838 to 1,208 feet in 1863 and the lower reaches of the Madhumati opened out considerably Sherwill and Fergusson in 1857 and 1863 anticipated, if the process continued, that the great outlets of the Ganges to the Sea would be through the Garai, Upper Kumar and Chandana rivers The Ganges between Kushtia and Goalundo could then be expected to silt up and become a huge jhil These anticipations were, however, never realised, the combined Ganges and Brahmaputra having apparently failed to make the Arialkhan, or the contiguous eastern branch, the main outlet, has, since Rennell's time, broken into the Meghna south of Rajabari and this became and remains the main channel of the Padma

New outlets of Ganges into the Bay anticipated in 1863

27 In his note Appendix 1, Mr. LaTouche put forward the very reasonable suggestion that the Brahmaputra originally may have been a much smaller stream than at present. One of its main tributaries, the Dihong, in the course of ages gradually cut back into its valley until it beheaded the Tsan Po,* which Burrard and Hayden both believe formerly flowed westward, and either issued through the northern Himalayas, or lost itself in the deserts of Tibet With this great accession to its supply, the Brahmaputra became one of the greatest rivers in the world, carrying down large quantities of silt and commenced delta-building activities on a large scale A great deal of work had, however, to be done in raising the Assam valley, and as this is being accomplished, the influence of the river on the lower portion of the Gangetic delta will become increasingly felt In this way Mr La Touche accounts for the comparatively less advanced condition of the eastern margin of the delta, taking into consideration at the same time the probability that at some remote period this region was covered by the sea and consequently generally lower than the western portion of the delta

Changes in course of Brahmaputra river

La Touche's theory of comparatively recent connection of Brahmaputra with Tsan Po

Causes of less developed state of the eastern portion of the delta

28 About the time of the irruption of the Tista into it above Dewanganj in 1787, the Brahmaputra deserted its old south-easterly Mymensingh course into the Meghna, to which Fergusson believed it to have been diverted by the elevation of the Madhupur jungle, and forced a passage south through the Jenai and Konai into the Ganges at Jaffarganj.† This change carried it from the eastern to the western side of the Madhupur Jungle, and probably took place gradually between 1750 and 1830.

Change of Brahmaputra from east to west of the Madhupur jungle area

* Dr Sven Hedin in his "Trans Himalaya" points out that a similar process is actually taking place at the head of the Kali Gandak which is very gradually cutting back into the Tsan Po through the Kore La He believes that a connection will naturally be established in the course of some thousands of years but that even now an artificial connection could be cut without much difficulty and this would bring down through Bihar a great accession to the water of the Ganges at the cost however of a diminished supply to the Brahmaputra

† Rennell in 1772 shows the Jenai as a small distributary branching off the main channel at Jamalpur and the Konai as a very minor spill stream, too insignificant to name, taking off the Brahmaputra just above Dewanganj Buchanan Hamilton about 1810 remarked that the Konai threatened to carry away Dewanganj and perhaps force its way into the heart of Nattore showing that the new channel must have been then actively developing The Jenai was also increasing and may, as Fergusson suggests, have been opening out for some years previous to Rennell's survey though there are no charts to confirm this view In Wilcox and Ommaney's survey 1830 to 1835, the Jenai has grown into a big stream and the Konai is an even larger river taking off westward at the mouth of the old Konai and then passing southward, joining the Jenai at Sursabari to form the Jamuna flowing into the Ganges at Jaffarganj The old main channel of the Brahmaputra had deteriorated very considerably and in the Revenue Survey, 1852 to 1867, it had silted up the Jenai by that time had also deteriorated and the main flow was down the Konai which had moved bodily to the westward

Changes in course of the Tista

29. The Tista in Rennell's time, about 1776, ran down from the Sikkim Himalayas past Jalpaiguri and flowing south, commingled with the Caratoa and Atrai rivers and passed into the Ganges near Goalundo. One branch, the Puranbhiba, joined the Mahananda near the latter's confluence with the Ganges. In 1787, not long before the diversion of the Brahmaputra, the Tista, which in its upper reaches is practically a mountain torrent, made a complete avulsion during an unusual flood and leaving Jalpaiguri to the west, flowed south-east in its present upper course, into the Brahmaputra. Probably this was, as Fergusson suggested, along an old bed of the river since Rennell shows a "Tista Creek" passing south of Ulipur above the position of its present junction with the Brahmaputra and a series of pools along this course. The mouth of the river has worked downstream considerably since that time.

Nadia rivers

30. There have been considerable changes in the Nadia group of rivers and probably only the Bhagirathi has remained fairly constant in its present direction. The Kumar formerly occupied a position something like that of the upper Matabhanga at present, and then flowing in a east-south-easterly course, emerged into the old Ganges near Madaripur. *Old Kumar river* It has since been cut across by the Madhumati and also the Chandana,* an offshoot from the Ganges at Kushtia, with the result that it has decayed over a great part of its course. The Bhairab, which in very early times was undoubtedly a most important river, ran from below the Bhagirathi offtake south-eastward past Jessore and Khulna into the Madhumati and Haringhata estuary. *Old Bhairab* About 300 or 400 years ago the Jalangi opened out across its course, taking the drainage south-west into the Hooghly, and lower down the Matabhanga cut across it, also running south-westwards. The upper Bhairab opened again in 1874 into the Jalangi, and recently the Jalangi offtake from the Ganges has practically closed, but the intermediate section of the Bhairab has died and the lower section decayed. In its lowest portion below Jessore, it now taps a large volume of the Kumar and Garai spill, but recently the south-easterly direction of the flow from Khulna to the Madhumati, has been changed and the Bhairab now takes the Atharabanka water from the Madhumati south-westward into the Rupsa and so through the Passur into the Marjata estuary.

Ichhamati river

31. The Ichhamati was probably a branch of the old Bhairab, flowing nearly south. Since the Mathabhanga opened up the Churni distributary to the south-west into the Hooghly, the Ichhamati has deteriorated. The Jabuna effluent, the relic of the old Jabuna branch of the Ganges, given off from the left bank of the Hooghly near Bansberia, which met the Ichhamati lower down, has closed in its upper course. *Old Jabuna river* The Jalangi and Matabhanga Churni are comparatively new rivers, the modern Churni having opened out since Rennell's time at the end of the 18th century.† They carried the spill from the Ganges in this region south-westward into the Hooghly instead of south-east into the Bay, as was the trend formerly. *Change in drainage of Nadia rivers*

Old courses of Damodar river

32. According to Sir William Hunter's interpretation of Vanden Broucke's map of Bengal dated 1660, one branch of the Damodar continued an easterly course at Burdwan into the Hooghly near Kalna. In the Bengali volume "Monshar Bhasan" by Khamananda Dass about 1640, the passage of the corpse of the hero from Burdwan, can be traced along this channel of the Damodar by the names of various villages it passes into the Hooghly on its journey to Mugra. Later the Damodar left this channel, continuing southwards below Burdwan and a main branch, after trending south-east, made a wide sweep to near Gopalnagar and then flowed in a north-easterly direction to enter the Hooghly at Noaserai, 12 miles south of Kalna. This branch apparently had no protracted life. Some time in the middle of the 18th century, according to Rennell, who shows this channel as an old bed in 1776, the Damodar deserted this course and the main stream followed its present direction southward into the Hooghly at Falta. It is at present being with difficulty restrained from reverting to its 17th century course from Burdwan into the Hooghly at Kalna.

33. Omitting the Kosi and Mahananda regarding which there are no available indications of the probable period during which the changes of their confluences with the Ganges took place,‡ the main recent changes in direction of drainage over the whole delta may be summarised chronologically as follows:—

Ganges diversion 15th century

34. Probably some time in the 15th century, the main branch of the Ganges was gradually diverted from a southerly course debouching into the western side of the delta, to a south-easterly direction into the Padma, flowing into the Meghna on the eastern side of the delta. About the end of the 17th century, the Damodar must have altered its easterly course to Kalna, to its peculiar course entering the Hooghly at Noaserai. *Damodar's change of course, end of 17th century* Probably more or less at the same time, the Jalangi opened flowing south-west into the Hooghly and cutting across the Bhairab flowing south-east. *Opening of Jalangi* In the middle of the eighteenth century, the Damodar again changed its main direction, now flowing south. *Damodar diversion, middle of 18th century* In 1787 the Tista was diverted from a southerly course into the Ganges near Goalundo to a south-easterly course into the Brahmaputra. *Tista avulsion end of 18th century* A few years later, the Matabhanga-Churni opened south-westward into the Hooghly and the streams in this region flowing south-eastward began to decay. *Matabhanga opens* From the middle of the 18th century the main stream of the Brahmaputra made a gradual change, flowing south into the Ganges at Goalundo instead of south-east into the Meghna. *Change of Brahmaputra course early in 19th century*

---

* Rennell refers to the Chandana as the deepest and largest of the upper distributaries of the Ganges. It has since completely degenerated.

† Rennell shows the Churni as a small branch of the Ichhamati entering the present Channel about Aranghata in a due westerly course.

‡ The Kosi according to Fergusson, who quotes from Buchanan Hamilton, originally combined with the Mahananda and flowed through the Baral-Atrai rivers into the Brahmaputra. Rennell recorded about 1779 that the Kosi at no distant date had flowed past Purneah and joined the Ganges 4[illegible] miles below its present mouth.

Opening of Garai-Madhumati

35. There is another change in direction of drainage which has not been mentioned by Major Hirst. As already stated, the old Kumar river continued its course to eastward of Faridpur flowing east-south-east. It was first intersected by the Chandana flowing south-east and quite recently in the early part of the 19th century, the Garai-Madhumati began to open out and take the spill in this region more freely south-east and southward. The Garai, as stated by Fergusson, was previously only a small local drainage channel: when a greater volume of water from the Ganges was forced into it, the channel could not accommodate the supply and serious floods in the Muhammadpur region mid-way between Jessore and Faridpur resulted seasonally at the end of the 18th century, until the river developed into a proper distributary Since Rennell's time the Kaliganga branch of the Garai at Kushtia has opened out; a new eastern distributary was thrown off south-eastward from Khoksa and this gave off a southern branch, the Hanu running into the old Kumar at Dareapur A new western branch has also been given off from the Garai, running into the Nabaganga at Ramnagar above Magura. The Alangkhali khal above Muhammadpur opened out between 1820 and 1830 and is now the main Madhumati channel and this has opened out a new channel, the Atharabanka, which Fergusson refers to as the Chitra, flowing south-westward into the Bhairab at Khulna. In its lower reaches the Bhairab also, as has already been seen, instead of flowing south-east from Khulna into the Madhumati has at one point, at Alaipur just below Khulna, been actually reversed in direction the Bhairab here is now dominated by the Atharabanka and flows south-westward into the Rupsa.

Opinion on Major Hirst's theory

36. These changes in the courses of rivers in the deltaic area require explanation. Major Hirst considers that the tectonic phenomena referred to in his report have been the main determining factor, the existence of these tectonic phenomena has, however, been refuted by Messrs Hayden and Pascoe and it seems, considering the conditions, the physical characteristics of the rivers, and of the country traversed by them, that the alterations in courses would find a simpler, more reasonable and quite satisfactory explanation in the ordinary well known processes of riverine and deltaic development.

Deltaic changes probably due to ordinary processes

Fergusson endeavoured to prove that during one phase of the development of the main valley, the confluences of tributary rivers tend gradually to work upstream until their direct ons assume positions nearly at right angles to the parent stream. He has traced the probable old courses of such rivers as the Mahananda, Kosi, Gandak, Sone and Gogra and the great changes which have taken place successively in the lower courses of these streams are shown on map No 1 Whether Fergusson's theory of causes be accepted or not, the uniformity of the changes, which in all cases show a movement of the mouth of the tributary, upstream, indicate that the influencing causes must have been purely natural and not connected with tectonic phenomena.

Natural diversion of Ganges

37 The main stream of the Ganges having in the course of ages raised the land surface on the extreme western side of the delta may by this very process have been naturally diverted gradually into the comparatively less developed regions to the eastward. It may have been further influenced in this direction by the change of course of the Kosi, which gradually carried that river westward until it discharged into the Ganges above Rajmahal

Changes of Damodar and Tista to be expected in the case of torrential streams

38 The Damodar and the Tista are torrential streams with heavy charges of silt and liable to floods of great severity but short duration. The channels of streams of this description are naturally unstable where they enter the level plains and commence to spill. Under these circumstances, avulsions such as have occurred on these rivers might be naturally expected in the course of time without any assistance from tectonic forces

39 As regards the Brahmaputra, it will be seen from the map that the old course past Mymensingh, described practically a semi-circle round the Garo hills spur. The present course flowing due south from Dhubri, at the head of the delta where the fall is still fairly considerable, is for a large deltaic river a more direct and natural course, which had probably been followed and raised in past ages When the Brahmaputra was reinforced at the end of the 18th century by the Tista entering opposite the face of the Garo hills, it is quite conceivable that it should be definitely deflected to the westward and naturally begin to open out this course again along the channel afforded by the Jenai river

Probable effect of Tista diversion on Brahmaputra

Changes in Nadia and Jessore rivers due to natural causes

40 The changes in the Nadia and Jessore rivers do not seem in any way inconsistent with the natural conditions of the delta, particularly when influenced by artificial causes induced by the spread of human habitation. It has been seen how, after the Brahmaputra poured its waters down its new course, spill offtakes such as the Garai and Chandana above the confluence responded in a perfectly natural manner and a new channel from the Madhumati, the Atharabanka, was opened in a south-westerly direction away from the supposed line of subsidence, though situated quite close to it

It may be remarked that in order to correspond with the direction of flow of the main rivers, Major Hirst's line of subsidence would need to be curved at the lower end to follow the Padda course into the Meghna, and even then there would be streams actually on the line, which flow in the wrong direction, such as the Nayabhangani, flowing south westward from the Meghna into the Arialkhan

Attempts at artificial control of Matabhanga

41 The rivers flow through a region of very flat, loose, alluvial soil and even trifling obstructions have at times a considerable effect on their directions. Artificial causes, such as the erection of embankments, clearing of forests and extension of cultivation would tend to control, or alter the tendency of drainage and this has to some extent been accountable for the decay of rivers in the Jessore district. The opening of the Matabhanga which might have been influenced by conditions in the Ganges below its offtake,

about the time the Brahmaputra was changing its course*, was maintained to some extent artificially by the action of the Superintendent of the Nadia rivers, and others, early in the 19th century, when they endeavoured to close the Kumar and other offshoots. It is now again discharging its spill supply more freely to the south-eastward through the Kumar and Ichhamati rivers, the heads of the remaining outlets having in the meanwhile completely silted up. It might be remarked that this is at a time when the Damodar is endeavouring to force its way again to Kalna and these two tendencies are inconsistent with the existence of any depression at Nadia.

Present behaviour of Matabhanga and Damodar inconsistent with theory of depression at Nadia

42. Spill rivers flowing through low marshy regions naturally tend to form high banks, or bund themselves in along their courses. In course of time if the silt charges in them are maintained, it is obvious the conditions would become unnatural and during heavy floods the tendency would be for the drainage to leave these channels and flow more freely into newer routes through the low lying adjacent districts.

43. In connection with the variability of the discharge of spill rivers, one point has apparently been overlooked, except for such recognition of it as is implied in the fact that offtakes situated in a concave bend or pool of the main river are naturally more favourably placed as regards discharge than when situated on the convex bank. This point, which seems to have an important bearing on the matter, is the effect of the continually varying slope of the Ganges on its spill offtakes As already mentioned, the Ganges slope is not uniform. It varies not only in different sections of the river at the same time, but even at the same place it must be in a state of continual change, in correspondence with the alterations of the river above and below it It is, therefore, natural to suppose that under abnormal conditions (such as exist at Sara), an offtake at a point where the slope of the main river is much reduced would receive a greater supply than usual As the conditions altered and the slope increased, the main river would carry a greater portion of its discharge past the entrance of the spill river and the supply through the offtake would be diminished This would account to some extent for the periods of good and bad years of the spill rivers There seems to be no question that the Ganges has straightened its channel from Rajmahal to the Meghna considerably since Rennell's time and the process is apparently still active This naturally tends to increase the slope of the main river and would be generally detrimental to its distributaries

Effect of variations of Ganges slope on offtakes

44 The major tectonic forces which have undoubtedly operated through ages in the gradual subsidence of the delta, may still be active, but this action would obviously be too slow and gradual to be taken into account in considering their influence on the drainage of the delta, though this might conceivably be effected in places, as the result of violent superficial tremors, or earthquake shocks There thus seems to be no necessity to seek an explanation for alterations of the rivers in any but ordinary natural causes and as such, susceptible to a certain degree to human control.

Effect of major tectonic forces on river system may be left out of consideration

45 This result of an examination of the geological features of Major Hirst's report does not in any way detract from the importance of the issues involved, nor does it diminish the necessity for a close examination of the problem Though disagreement with Major Hirst as to the causes may be fundamental, the effects which he has attributed to these causes may still be as serious and real as he has presumed them to be They thus require the most careful consideration as the importance of their possible influence on the future of the Port of Calcutta cannot be over emphasised

CHAPTER II.

Development of the Delta and of the Nadia Rivers.

Major Hirst classifies the rivers of the delta in three main types .—

Major Hirst's classification of main river types

(*i*) Those in the upper part comprising the tributaries of the Ganges flowing down into it from the base of the Himalayas these he regards as top dressing rivers engaged in raising the land on the flat plinth on which he presumes Bengal to have been built

(1) Top dressing rivers

(*ii*) "Plinth" rivers flowing through the lower, or practically flat portion of the delta proper, with building functions which extend the delta face This action being dependent on tidal forces, there occurs in this area a predominance of north and south streams and a gradual extinction of east and west channels The north and south rivers, though more tenacious of life, are dependent on the force of fresh spill water, and if this becomes insufficient to combat tidal action and so interferes with the delta building functions, the rivers are likely to die.

(3) Land denuding rivers

(*iii*) Land denuding rivers of the type of the western tributaries of the Bhagirathi

2. It is difficult to understand the distinction made by Major Hirst between Classes (*i*) and (*ii*), as both types denude the high land ; in the one case the Himalayas and in the other, the high ground of Chhota Nagpur and neighbouring districts to the west, and both are engaged in top dressing, or delta building operations in their lower reaches, as shown markedly in class (*iii*) by the Damodar. Other rivers of this type such as the Dwarka and Ajai are raising their spill areas, or deltas, appreciably. In other words both these types simply fulfil the ordinary functions of a river

Classes (*i*) and (*iii*) similar and fulfil ordinary functions of a river

* The Matabhanga continued open every year from 1809 to 1818 and was more easily navigable than either the Bhagirathi or Jalangi

Debatable rivers include Nadia rivers

3. Between the plinth rivers and those engaged in top dressing operations, Major Hirst places a "debatable" type of river comprising the spill channels of the Ganges from the Bhagirathi head to Goalundo. Owing to the transverse course of the Ganges, he considers that these streams are cut off from heavy spill and consequently are incapable of top dressing the plinth to the south this, he argues, is proved by the fact that the delta face in this portion shows no signs of progressive extension The whole area of Murshidabad, Nadia and Jessore between the Bhagirathi-Hooghly and Madhumati has in this manner become decadent and is likely to remain so, until the Ganges adopts a more favourable course, and in this area the most difficult problems of drainage, etc., occur. The Bhagirathi, Jalangi and Matabhanga are consequently more or less debatable rivers and though the Bhagirathi is capable of raising portions of Murshidabad to its east, this action is constrained by embankments The Hooghly which is formed by the debatable Nadia rivers and the land denuding tributaries from the west, flowing into the lower section which is a "plinth" river of the north and south type, is consequently presumed to present an unusually complex regimen.

Hooghly a composite river with a complex regimen

Apparent discontinuance of delta formation in the west of the delta

4 The whole argument here appears to rest on the apparent discontinuance of delta building operations on the western face of the delta The process under ordinary conditions is an extremely gradual one and very careful and accurate series of surveys of the sea face with the soundings to the 20-fathom line would be required to detect any noticeable differences in the short period of half a century or so, in which we have more or less reliable records

Mr B M Samuelson's "Note on the Irrawaddy river"

5 Mr B M Samuelson in his "note on the Irrawaddy river" published in 1915, has collected information on this subject with reference to various rivers, and in the case of the Nile where the evidence is obtainable by the depth of silt deposit on ancient temples and cities over a period of centuries, he says "Hewson states that the delta of the Nile which was not embanked has only extended seaward two miles since the time of Herodotus and has now ceased altogether During the Christian era while the matter deposited by the overflow of the Nile has raised the surface of Egypt by 4 inches per century, the bed of the river has also been raised at the same rate at Damietta where the elevation from the overflow is imperceptible the elevation of the river bed and bank is imperceptible At Cairo, 120 miles from the mouth where the flood level is 25 feet above low water mark, the elevation of the land is, since the Christian era, 5 feet 10 inches. At Thebes, 500 miles from the mouth, where the flood level is 36 feet above the low water line, the land and river bed have been elevated 7 feet, while at the first cataract 100 miles higher upstream, the levels of the bed and banks have been raised during the same period as much as 9 feet The Nile is now enclosed by embankments from Assuan to the Sea." The delta of the Mississippi extended into the Gulf of Mexico, a distance of 2 miles from 1724 to 1824, at an average rate of 96 feet a year Since the extension of embankments, the rate of progress is said to be now 300 feet per annum at the South-West Pass, 260 feet at the Pass a l'Outre and 100 feet at the South Pass Since the Christian era the extension of the delta of the Po and Adige into the Adriatic has been 20 miles. Before embanking was commenced, the rate was 22 feet a year While the embankments were being extended, between the 15th and 17th centuries, the rate was 82 feet per annum and since the embankments were completed, the average extension for 200 years has been 230 feet annually

Delta of the Nile

Delta of the Mississippi

Deltas of Po & Adige

Deltas of Danube, Rhone and Volga

6. Before the regulation of the channels of the Danube, the delta advanced 200 to 300 feet per annum at the Kilia mouth and 94 feet per annum at the Sulina mouth. The regulation of the mouth of the Rhone caused an increase in the rate of progression of the bar seaward from 76 to 290 feet per annum and this led to the abandonment of the regulation works The extension of the Volga delta into the Caspian Sea at the rate of 1,270 feet per annum is the greatest on record The "Indus" which is largely embanked extended its delta 133 feet annually between 1873 and 1904.

Deltas of Indus & Irrawaddy

7 For the Irrawaddy, which is not embanked, Mr Samuelson gives a rate of extension of the three and five fathom-lines at the mouth, of 3½ to 4 miles in a century of the 10 and 15 fathom-lines, 1 and 1½ miles and of the 20 fathom-line, 3 miles in a century. In the Gulf of Martaban to the eastward, off the ports of Rangoon and Moulmein, where the major portion of the deposit is presumably carried by the tidal currents and storms, he gives rates increasing from 5 miles for the 5 fathom contour to 35 miles in a century for the 20-fathom contour. This would indicate a serious state of affairs for the futures of those ports but there is a probability of error in the surveys

Influence of tidal currents on delta formation

8 It is evident, therefore, that the rate of extension of the delta of any great river with a free spill is very small and though this depends on the silt charge, it is influenced to a great extent by the tidal and other conditions obtaining off its mouths Where the sea into which the river issues is shallow, the rate will naturally be considerable and particularly so, if there are no tidal currents dispersing the alluvium on its discharge. This is the case with the delta of the Volga In the cases of the Nile, Po, Danube, Rhone and Mississippi, the tidal rise is either non-existent or very small. The rise of tide off the Irrawaddy delta is 7½ feet on a spring tide at Diamond Island and nearly 19 feet at Elephant Point at the mouth of the Rangoon River These conditions tend to disperse the discharge of the Irrawaddy eastward over the head of the Gulf of Martaban and there is in consequence a much slower growth seaward off the actual delta The Irrawaddy with an extreme maximum discharge of about 2,000,000 cusecs in the flood season, with a silt charge of 1 to 1,840 by weight, carries its delta forward about 200 feet a year.

9. Off the mouth of the Indus, the tidal range is 9½ feet in springs at Manora Point, Karachi, and from seaward, a deep hollow, or Swatch of No Ground, runs in toward the coast. With a discharge varying from 17,000 to 1,000,000* cusecs and a silt charge of 1 to 237 by weight in the flood season, the rate of extension of the delta face is 133 feet a year The conditions off the Gangetic delta are somewhat similar to those at the mouth of the Indus A similar deep gutter or Swatch of No Ground runs up the head of the Bay of Bengal in a north-easterly direction parallel to the Orissa Coast Though the term would lead one to expect considerable depths in this trough, it is actually deep only in comparison with the shallow regions close on either side. The depth over the lower portion of the Bay is about 2,000 fathoms and this gradually shoals upwards in the middle of the Bay, till at the bottom of the Swatch the depth rises to 600-fathoms. Near the head of the Swatch, the sides of which gradually converge, the depth is 239 fathoms in Lat. 21 15½ N. and only 5 miles away from 20-fathoms on the western side. The 100 fathoms line at the apex of the Swatch in Lat 21° 24½ N reaches to within 20 miles of the Sea face and the depth here rises sharply to 10 fathoms in 4½ miles.

Swatch of No Ground off mouth of Indus

Swatch of No Ground at head of Bay of Bengal

10. The influence of this deep trough on the tides and currents at the head of the Bay of Bengal would appear to be fairly obvious Arguing theoretically, the centre of the tide wave advancing up the Bay should, according to the laws of wave motion, travel fastest up the central deep trough Reaching the head of the Swatch, the tide wave would then fan out on either side across the face of the delta and after flowing its full period, high water would occur earliest where the tide came in, at the apex of the Swatch the wave would then recede through the depression in the reverse manner to its approach. This theoretical argument appears to be fully confirmed by the observed directions of the current at different points across the head of the Bay It will be seen on Map No 1 that the direction of the first of the flood tide is everywhere always away from the head of the Swatch, while the first of the ebb on the contrary sets from opposite ends of the delta face towards it. Low and High Waters must accordingly occur earliest at this position Observations to verify this would need to be taken in the same latitude and in deep water as the tide wave is greatly modified according to local conditions, as it enters shallow water. The set of the flood and ebb tide from and towards the Swatch is further confirmed by the directions of the entrance channels of the deltaic rivers which, as will be seen on Map 1, in every case without exception trend towards it, even from opposite sides of the delta Fergusson, whose lead in this matter has been generally accepted hitherto and has been followed by Major Hirst, appears to have been misled by taking the times of high water, instead of the directions of the current at different points, to show the approach of the wave He consequently argued that two portions of the tide wave advanced up either side of the Bay and meeting in the centre at its head, retired down the Swatch. This would presume that the wave travelled quicker in the shallow water of the coast than in the central deep portion of the Bay and if the tidal wave made first near the coast, it would likewise ebb first along the shore and would not retire down the Swatch

Influence of the Swatch on the tidal wave

Trend of river channels towards the Swatch

Fergusson's view of behaviour of tidal wave

11. The existence and position of the Swatch which indicates by its character and slopes, a gradual filling in by deposit from either side appears to show, as before stated, that no main branch of the Ganges can ever have debouched for any length of time through the middle of the delta, this hollow may approximate therefore to the original depth of the head of the Bay

Indications of Swatch

12. As the deep water reaches so close to the outlets of the Garai, Kumar and Ichhamati rivers with a constant strong tidal flow through it, any silt carried down by these rivers instead of settling off the mouths of the Haringhata and Raimangal estuaries would be dispersed, or carried away through the Swatch The silt, however, brought down to the Sea by the Jessore rivers cannot be a very considerable quantity. The Garai, Madhumati (and formerly the Chandana) are really active spill rivers and though such streams as the Nabaganga, Chitra, Bhadra, and Kobadak have been beheaded at their offtakes from the Matabhanga, two other distributaries of the latter, the Kumar and Ichhamati, still bring down the greater portion of its supply, but the alluvium from these live streams particularly, and the Garai to some extent, is deposited on its way in the innumerable bils and spill channels in the Jessore district, so that the water is discharged into the estuaries to a great extent strained of its silt contents The bils are very gradually being silted up, the supply through the Garai and Kumar being at present sufficient for all purposes of drainage, sanitation, etc, and as Mr Addams-Williams has pointed out, the river systems in the Khulna section, Faridpur, eastern half of Jessore and Bakarganj districts, by a proper application of drainage methods and utilization of tidal flow, are now being maintained in an efficient state The extension of the principles of conservation worked out for this portion to the rivers, further west to the 24-Parganas and western portion of the Jessore district, is expected to effect a similar improvement Meanwhile, however, as the rivers are engaged in top dressing operations in Jessore and carry little silt to sea and as the amount so discharged is swept over the Bay, the middle portion of the delta cannot advance

Effect of Swatch on discharge of Jessore rivers

Filtering of discharge of Jessore rivers through bils and spill channels.

River system of Khulna section maintained by proper methods of conservation

13 On the western side of the delta, the progress is naturally very slow since the Ganges main channel has been diverted and is now masked by active erosion of the land face by wave action. The changes are shown on Map No 1 and more in detail on Map No. 6, where the considerable erosion of the southern face of Saugor Island reaching a maximum of 4½ miles since 1770, and a general erosion of the sea face of Saugor Island

Advance of delta off mouth of Hooghly Erosion of land face

* The average discharge during the inundation season from June to September is 386,000 cusecs

Formation of islands below Saugor

and Frederic Island to the eastward, of 2 miles since 1840, are tinted green and red, respectively. It might be expected if the delta was advancing, that islands would appear off the mouth of the Hooghly and such are actually in existence on the Long and Saugor Sands to the south-west and south-east of Saugor Island, but these have a considerable struggle to maintain themselves against surface erosion, so that they have no permanent existence.

Edmonstone Island a pilot station, 1820-30

14. They appear and disappear as in the case of the Edmonstone Island on Saugor Sand. This, according to Horsburgh, grew in 1817 from a half tide sand bank to an island two miles in length and half a mile in breadth and affording a supply of fresh water. It appeared so substantial that it was adopted as a station where a pilot resided in 1820 and in 1825 a proper house was built on it. A cyclone in May 1830 commenced to destroy it and it was abandoned as a pilot station in 1831 Another cyclone in May 1833 divided it into two portions and by 1841 the island had completely disappeared. It formed again subsequently and a smaller islet appeared further southward about 1888. Both islands increase and diminish in extent, and are now of moderate size On the Long Sand on the opposite side of the channel, islands with a fair amount of vegetation have sprung up and been washed away at intervals.

Sandheads

Ritchie's chart, 1770 Lloyd's chart, 1837-40 Hooghly River Survey chart, 1910-11

15. The 5-fathom contours on the tails of the sands may, however, be taken as the feelers of the real foundation of the delta For a comparison of these we have three surveys made at intervals of 70 years The earliest, Ritchie's survey of 1770, cannot be regarded as very accurate and has had to be adjusted in most places. The tails of the Sands, however, are probably fairly correct in latitudinal position as they were the guides across which vessels found their way into the channels in those days. Lloyds' survey, the next, in 1837-40 was apparently based on astronomical observations and the area was again mapped by the Hooghly River survey in 1910-11 on a triangulated basis.

Extension of 5-fathom line

16 Between 1770 and 1840 the 5-fathom contour of the Eastern Sea Reef on the western side of the Eastern Channel, travelled down 4 miles at an average rate of 317 feet a year. The Middle Ground between the Eastern Sea Reef and Eastern Brace progressed 6½ miles and the tail of the Eastern Brace on the western side of the Western Channel was washed up 3 miles Between 1840 and 1910, the 5-fathom contour of the Saugor Sand on the eastern side of the Eastern Channel, extended down 1¾ miles or 137 feet a year. The growth of the Eastern Sea Reef diminished to 150 feet a year, but the Middle Ground maintained its former rate of extension of 960 feet a year and travelled down another 6½ miles the Eastern Brace remained stationary The upper part of the Eastern Channel which had filled in considerably between 1770 and 1840 opened out in the following period A patch of the ten fathom contour below the tail of the Saugor Sand, progressed seaward 2½ miles between 1840 and 1910 and a slight extension of the 20-fathom line eastward of the Eastern Channel was balanced by a recession on the western side

Indications that the Hooghly and its tributaries are still active delta building streams

17 The evidence indicates that the delta forming functions of the Hooghly with its feeders and tributaries, are by no means inactive at the present time The general tendency seems to be a progression on the eastern, or Swatch of No Ground side, at the rate of about 130 feet a year with a considerable local growth at the rate of 960 feet a year at the entrance of the Western Channel This has been accompanied by a slight general retrogression of the 10 and 20 fathom lines on the western side of the Sandheads The decrease in the general advance in the period, 1840 to 1910, as compared with the earlier period 1770 to 1840, is probably due to the opening in 1856-59 of the country below its right bank, to the spill of the Damodar, which has so largely absorbed that river's delta building activities and further to a probable decrease in the spill supply of the feeders. The extension of the embankments on the Hooghly has not counteracted these effects, as the Hooghly's spill has apparently for a long period been restrained by its high and well formed banks with the ordinary zemindari bunds, and the raising of the embankments in the lower reaches was designed simply as protection against storm waves. Should the Damodar break into the Hooghly at Kalna as is possible, and measures be successful in obtaining a greater supply through the Nadia rivers, a more rapid extension of the delta on this side may be expected, but the conditions will still be favourable for the maintenance of a good entrance channel to the Hooghly for a considerable period. This is particularly noticeable in comparison with the conditions on the opposite side of the Bay.

Embankments of Hooghly

Conditions favourable for maintenance of good entrance channels

Condition on eastern side of delta

18. The most marked advance should under present conditions take place over the eastern portion of the delta where the combined main rivers issue into the Sea As will be seen on the map, to the eastward the southern face of Sandwip has been washed away about 6 miles since Rennell and Ritchie's survey, but a small islet has formed near the southern limit of the former main island. In the middle, there has been considerable growth and Nalchira island and others in South Hatia have extended down sixteen miles and the southern end of Dakhin Shahabazpur about ten miles since 1764-1773. Elsewhere alluvion in one place has been balanced by erosion in another. To seaward, however, if Lloyds' survey of 1837-40 and the Admiralty chart of 1877-80 are strictly comparable and referred to the same datum value, it will be seen that a great patch. 45 miles by 15 miles, had been filled up in the 40 years between 1840 and 1880, carrying forward the contour over the western portion of the 5-fathom bay on the Chittagong coast The 0-fathom line has extended very slightly and there has been no appreciable change in the 20 fathom contour. The advance of the 5-fathom line which is in the nature of a 'fan' thrown down in the shallower water, now encloses a vast area on the eastern side of the Bay and threatens within a hundred years or so, to obliterate the deep water on the Chittagong coast, and the advance of the sea face off the mouth of the

Growth of delta foundation off mouth of Meghna

Meghna should then proceed rapidly. The nature of the sea bed off the western portion of the delta is characterised by the deep flood channels, one or more in number running up into each estuary, between wedge shaped sands stretching out into deep water where the 10-fathom line becomes regular. On the eastern side it will be seen these 5-fathom channels have been entirely obliterated, leaving remains of 3-fathom channels only; the 5-fathom contour instead of being deeply indented as on the other side, has spread out like a fan, leaving the sea bed uniformly shallow except for a deep gutter running up inshore along the Chittagong coast This 5-fathom line here is practically as regular as the 10-fathom line to the westward The 500-fathom line also fans out much further into the Bay than on the western side This progression of the delta, if actual, is remarkable, for even considering the enormous discharge of the combined rivers and the high silt contents, it must be remembered, the rivers spill freely and their land building activities must be largely absorbed before they reach the sea The advance of the delta in this region must in the course of time affect the direction of the Ganges outlet, as this river is weaker than the Brahmaputra and has at present a very much longer lead to the mouth

19 Major Hirst's debatable rivers in the Nadia and Jessore districts may therefore be regarded as actually spill streams in a more or less quiescent state It is not improbable that they would, if left to themselves, pass the critical stage when they could be affected by a change in the Ganges, and would gradually be extinguished, but under present conditions and with ordinary care they should last, and may at any time resume their activities in accordance with changes in the main stream In some cases, such as the Nadia rivers, the Garai and the Matabhanga offshoots, they are still capable, as has been seen, of fulfilling their top dressing functions and are yet far from having reached the stage when the possibility of the rivers degenerating into mere drainage channels would have to be seriously considered

Debatable rivers actually more or less inactive spill streams

20 It may be remarked here, that in addition to those classified, another type of deltaic river may be included, as pointed out by Mr Addams-Williams, and this is the tidal river which by carrying back the eroded material from the sea, builds up a plane sloping in from seaward in a contrary direction to the plane of the spill streams These rivers which comprise all the Khulna and 24-Parganas estuaries, being identical with Major Hirst's "plinth" rivers, are a further factor in retarding the extension of the delta on the western side Frequently the same river when not embanked may combine both top dressing and tidal dressing functions in different seasons When embanked, the material from the sea banks in suspension is carried up the channel and should the river have no spilling bil, or fresh head water-supply, to reinforce the downward swing of the current, it is deposited in the bed and the river naturally deteriorates. The Hooghly being a tidal river with embanked channels for the most part, and therefore, not subject to any tidal spill in its upper reaches, is therefore dependent above Fulta, on the maintenance of its fresh water-supply which is chiefly derived from the Nadia rivers

Tidal rivers identical with "plinth" rivers

Functions of tidal rivers

Hooghly a tidal river and therefore dependent on the Nadia head water

21 The Nadia rivers, Bhagirathi, Bhairab-Jalangi and Matabhanga being the first spill streams of the Ganges and situated furthest from its outlet, might be expected in the present phase of the natural development of the delta, to be the distributaries primarily liable to degeneration in the normal course Being almost entirely dependent on the spill supply and flowing through country which has been raised and settled for centuries, they have naturally had precarious lives and have consequently caused anxiety from time to time The country adjacent to the banks of the Ganges must be appreciably, though gradually, being raised, but the spill rivers have always found channels through the bank by way of vents, or depressions, probably remains of old courses and consequently the flow of water during the flood season has always been sufficient to give ample depths in the feeders of the Hooghly In the dry season, however, when the level of the Ganges falls low, the supply from the main stream under unfavourable conditions might be completely cut off, owing to the entrances drying up.

Nadia rivers first of spill streams liable to natural deterioration

2 This in each case depends almost entirely on the directions of the main stream immediately above and on the positions of the offtakes, which if favourably inclined on the concave bank with the main, or a loop channel, passing close alongside, might be expected to keep open On the other hand if the intake is inclined downstream and more so, if the main Ganges channel lies on the opposite bank and the Ganges level is low, the entrance will almost certainly be blocked by sand banks. The flow of any water into the feeders may then be entirely stopped and will not be resumed until the Ganges level has risen again in the usual course sufficiently to overtop the obstruction at the entrance The real; permanent entrances of the Bhagirathi and Bhairab-Jalangi are at Geria and Akriganj, respectively, but according to the position of the main Ganges channel, prolongations of the intakes are carried to it through the diara land of the Ganges These prolongations are naturally subject to constant change in position and the mouths of the feeders therefore shift from time to time over a considerable length of the main river channel in accordance with changes in the latter. The variations are exemplified in the case of the Bhagirathi in Map No. 3. It will be seen that the position of the entrance has varied longitudinally from Faracca to Geria, a distance of 25½ miles, and diagonally for about 10 miles. The Bhairab entrance has altered similarly, but not to the same extent, an example being the change in 1893 and 1894 when the entrance shifted from below Maricha to above Akriganj.

Conditions dependent on offtakes

Permanent entrances

Prolongations of entrances lying in diara land of Ganges liable to frequent changes

Variations of Bhagirathi entrance

23. In the development of all offtakes there appears to be a natural tendency for the entrance to progress downstream until it becomes merely a back water. When open fair to the current, the lower part of the entrance, being more exposed, is cut back, the mouth

Movement of spill offtakes downstream

widens and deposit takes place extending the upper point In this way, the entrance travels gradually down, first becoming square to the main river and then inclining downstream In this position scour is naturally reduced to a minimum and the whole entrance gets blocked by deposit The river passes through a bad phase until a new entrance channel is developed, either by an old course opening out, or the main river cutting into the spill channel at another point and forming a new entrance This happened in the case of the Matabhanga which according to Lang for many years previous to 1850 branched off from the Jalangi at Bausmari In November 1850, the Ganges main current cut into a bend of the Matabhanga above Jutpara and formed an independent entrance, which took a great supply and kept the river as far as the offtake of the Pangasi in better condition than either of the other feeders The entrance is now again through the old Jalangi mouth It also occurred in the case of the Bhairab where the Ganges channel cut into the Kulkuli river.

First reference to Bhagirathi head, 1666

24 It is, therefore, not surprising under the circumstances that the entrances of the feeders should have been subject to periods of good and bad years. The first mention which can be traced of obstruction to navigation is a reference as far back as 6th January 1666 by the French traveller, Tavernier, who records in his "Voyage in India":—

Tavernier

"Le 6 estant arrive a un gross bourg appelle Donapur a six costes de-Raje mehale, j'y laissay Monsieur Bernier qui alloit a Casembazar et da la a Ogouli par terre, parceque quand la riviere est basse, on ne peut passer a cause du grand banc de sable qui est devant une ville appelle Soutique"

It, therefore, appears that 250 years ago and probably somewhat about the same time since the main Ganges deserted this channel, the Bhagirathi entrance was practically dry early in the cold weather In this connection, it will be remembered that less than 50 years after the change of the Brahmaputra course, the old channel of that river had for the greater part completely silted up

Rennell, 1772

25 Rennel and his assistants were occupied in making surveys in Bengal from 1764 and in his "Account of the Ganges and Brahmaputra," published in 1781 when the entrance of the Bhagirathi was at Suti, as Tavernier found it in 1666, and the entrance of the Jalangi was at Jalangi, he records "The Cossimbazar (Bhagirathi) river is almost dry from October to May, and the Jellinghy, though a stream runs in it the whole year, is in some years unnavigable during two or three months of the dry season, so that the only subordinate branch of the Ganges that is at all times navigable is the Chundnah river which separates at Moddapur and terminates in the Haringhata river"

Capt Colebrooke 1797

26 During this time on his chart attached to the account, he shows the Jalangi as the only regularly navigable river and the Bhagirathi as navigable only in the flood season Captain Colebrooke in 1797, one hundred and twenty years ago, stated "The Bhagirathi and Jalangi are not navigable throughout during the dry season There have been instances of all these rivers continuing open in their turn during the dry season The Jalangi used formerly to be navigable during the whole or greater part of the year The Bhagirathi was navigable in the dry season of 1796 The Matabhanga when surveyed in 1795 was navigable throughout in the dry season, for boats of moderate burden This year (1797), however, I was informed that the passage was no longer practicable for boats proceeding to Calcutta. Experience has shown that none of these rivers are to be depended on" At that time there was no supervision over the Nadia rivers, apparently no bandalling was done and snags were not cleared from the channel, so that under natural conditions the necessary depth of only 1' to 3 ft required for laden country boats was not generally obtainable However, there appears from Rennell's statement usually to have been some flow through, though it may have been a mere trickle The Mathabhanga appears to have been the best of the three rivers in the early years of the 19th century and remained open from 1809 to 1818

Opening of Matabhanga, 1795

27 It will be remembered tha Captain Colebrooke stated that the Matabhanga when surveyed in 1795 was found to be navigable throughout the dry season So apparently previous to that year, it was not recognised as a regular river route to Calcutta and though Rennel shows it as a channel during the flood months, he refers to the Bhagirathi and Jalangi and makes no mention of the Matabhanga in his "Account" The connection between the opening of the Matabhanga, the great floods in the Muhammadpur region of Jessore between 1795 and 1801 (the flood of 1798 being the highest within living memory) which have been attributed to the opening of the Garai, and the breaking through of the Brahmaputra into the Ganges at Goalundo which was taking place about that period, cannot be avoided Wickes' view as quoted with approval by Major Hirst that the influence of the Brahmaputra could not be felt as high up as the entrances of the Nadia rivers, appears to overlook certain facts. His first argument that the beds of the Ganges and Brahmaputra are of soft material and the bed below Goalundo would accommodate itself by increased scour to any floods coming down the Brahmaputra without the water backing up in the Ganges, does not take into consideration that when the Brahmaputra first joined the Ganges, the combined rivers must have found the original outlet through the Arialkhan, and contiguous branches, insufficient, and the result was that a new and straighter channel was forced to the northward through the Kaliganga or Kirttinasa channel into the Meghna This must have taken some time and it was while the outlet was obstructed and increased scour was providing an adequate channel, that more water was forced down the upper distributaries. When a statisfactory outlet channel developed, the influence upstream would naturally not be so marked.

Synchronism of opening of Matabhanga and Garai and diversion of Brahmaputra

Muhammadpur Floods, 1795 to 1801

Examination of Wickes' opinion that entrance of Brahmaputra at Goalundo could not affect upper distributaries

Development of new Padma outlet into Meghna

Muhammadpur floods coincident with opening of Matabhanga and indicates that date of junction of Jamuna as main stream was about 1795

28 The second argument that if any backing up actually occurred, the Garai and Chandana would have taken the excess water, is met by the fact that these rivers actually did take a great part of the supply, but their channels were insufficient to accommodate it all, as is proved by the Muhammadpur floods. It is a remarkable coincidence that at the same time the Matabhanga showed signs of increased activity. This would fix the date of the first actual junction of the Jamuna as a *main* river at about 1795.

The third argument is that a raising of the Ganges flood level of six feet at Goalundo by the Brahmaputra would, according to the fall of the Ganges of 3·3 inches to the mile, cause no appreciable backing up at the distance of 95 miles up stream where the Matabhanga takes off. It would be difficult to estimate the actual extent the flood level was raised at Goalundo, considering the obstructed state of the outlet at that time, but the argument loses sight of the fact that though no actual backing up might take place 95 miles upstream, the raising of the flood level by even six feet would reduce the general slope of the main river from 3·3 inches to 2·5 inches to the mile. Any distributary at this point with a favourably placed intake would, by providing a greater slope, attract an increased volume of water.

Back water effects of Jamuna entrance as calculated by Ruehlemann's formula

29 Taking Mr Wickes' figures as quoted by Major Hirst as correct for the time, that is, with the Matabhanga head 95 miles above Goalundo, a fall of the Ganges of 3·3 inches per mile and a raising of level of 6 feet at Goalundo, and assuming the depth in the Ganges to have been 30 feet, Mr Addams-Williams by applying Ruehlemann's formula for back water curve, has deduced that a rise of about 7 inches would have been caused at the Matabhanga offtake. If the depth in the Ganges is taken as 40 feet the rise would have been 1′ 4″. For the Garai head 45 miles above Goalundo the corresponding rises would have been 2′ 3″ and 2′ 9½″ respectively. The backing up effect would therefore have been quite considerable.

Effect of Wickes argument on Major Hirst's theory

30 Furthermore, if a sudden raising of the river level 6 feet could not affect the supply of distributaries 15 to 90 miles upstream, it is difficult to understand how the very gradual raising of the ends of Major Hirst's elevated blocks Nos II and IV which can, judging by the general appearances, have not been very much more at the critical points, progressing at a rate of a fraction of an inch a year, could have affected the Brahmaputra and Tista at their points of diversion. The extremely gradual backing up in these places might be presumed to have been much more easily compensated for by increased scour.

History of Nadia River channels Matabhanga 1813-1818

Complaints of obstruction by merchants of Calcutta, 1818

31 In 1813 measures were taken to improve the channel of the Matabhanga and tolls were levied, but by 1818 the obstructions had become so bad that the merchants of Calcutta found their business seriously interfered with and petitioned Government to take steps to improve the rivers.

Origin of Nadia Rivers Division, Public Works Department, 1819

Kumar takes 5/6ths of Matabhanga spill

Removal of snags

32 In 1819-20 Mr C K Robison was appointed Superintendent and Collector of the Matabhanga and out of this appointment has grown the Nadia Rivers Division of the Public Works Department. The training of channels by means of "bandals" was commenced and an unsuccessful attempt was made to divert into the Matabhanga the current of the Kumar which carried away five-sixths of the supply. Mr May relieved Mr Robison in June 1820 and turned his attention to the snags which encumbered the channel and caused innumerable wrecks. During 1820-21 three hundred of these snags consisting of trees and wrecked boats were removed and trees on the banks which were likely to fall into the river were cut down.

Artificial closing of Kumar intake

33 The Matabhanga was made navigable from the entrance to the mouth of the Kumar till the end of March 1821 and as that river still took away three-fourths of the supply, an endeavour was made to close it. A caisson and some old boats were sunk across its mouth and a cut of 1,510 yards was made across a bend of the Matabhanga in order to attract the water. The result of these operations was that the Kumar intake closed and throughout 1821-22 a least depth of 3 feet was available throughout the Matabhanga.

Dredging machine employed on Matabhanga, 1823

Supervision extended to Jalangi and Bhagirathi, 1821

34 Mr May reported at the time that it would be difficult, if not impossible, to make the Nadia Rivers permanently navigable, owing to the great changes which took place in the Ganges channel at their intakes. He thought with two dredging machines of twenty horse power, he could keep one of the rivers open for boats of about 3 feet draft. A dredging machine drawn by bullocks was supplied at the beginning of 1823, but though it only drew 2 feet 4 inches, it was taken up the river with great difficulty, owing to the deterioration of the channel and the entrance was found so obstructed by sand that the dredger could not be used. The Jalangi entrance was open with 10 feet in December 1823 and 4 feet was obtainable throughout the river. The Bhagirathi entrance at this time, as will be seen on Map 3, took off the main channel about 8½ miles east of Faracca and was very favourably placed, the dredging boat was accordingly set to work there and in 1824, Mr May was given the additional charge of the Bhagirathi and Jalangi with a regular establishment for the purpose.

Bhagirathi, 1824-25

Ganges main channel takes Bhagirathi entrance, 1825

35 The Bhagirathi closed in March and the Jalangi in May 1824, but after the rains of that year the Bhagirathi entrance had shifted 4½ miles to the westward towards Faracca where it lay in the direct line of the main stream current. The entrance was cut through rapidly, widening from 250 feet to half a mile, and deepening to 22 feet in January 1825. In spite of this, however, the depth on the shoals down to Nadia was kept by bandalling at only 3 feet throughout the dry season. The Jalangi provided that year a depth of a little over 2 feet, but the Matabhanga closed and below the Kumar river was practically dry. In 1825 the main Ganges channel cut through a loop and shifted to a more direct course right through the Bhagirathi

entrance, leading diagonally across from four miles east of Faracca The new entrance to the Bhagirathi now took off the main channel 8 miles south-east of the old position this closed early in November 1825 and though a second dredge was supplied, all the rivers closed in March 1826 The entrance of the Bhagirathi worked gradually downstream, as shown on Map No 3, and in spite of dredging and cuts, was impassable except by small boats before the end of December each year and in February 1829 the depth was only 1½ feet At the end of the latter year the river had worked down into the old entrance channel of 1823, but this made matters no better and before January 1830, it closed and in November the bed was nearly level at many places with the surface of the water of the Ganges From the entrance to Nadia there were 23 shoals with little more than 2 feet depth and this state of affairs continued throughout the dry season of 1830-31. In the meanwhile, the Jalangi, which had closed for a part of 1826-27, had improved In 1827-28 sufficient depth was available during the greater part of the dry season for boats of 2 feet draft and this traffic was maintained throughout the following dry seasons, till in 1830-31 even large boats were able to navigate the river till the end of December

1826-1830

Pangasi branch of Kumar opens after closing of latter's offtake

36 After the closing of the Kumar offtake in 1820-21, the Pangasi which branched off from the Matabhanga lower down and ran into the Kumar, began to take the greater portion of the spill to the south-eastwards and by 1824 the position was the same as before the Kumar was blocked, the greater part of the Matabhanga water passed into the Pangasi, leaving the channel of the former nearly dry below the offtake.

Steam dredge tried in Matabhanga, 1828

37 The Matabhanga was in a bad state from 1825 to 1830 and two attempts to divert the water flowing away through the Pangasi proved unsuccessful and in 1828-29 a steam dredge was tried below the entrance of the Kumar without much result, owing to unsuitable machinery and the heavy draft of the boat which was 6 feet

1831-34

38 In 1831 early rainfall considerably increased the discharge of the Bhagirathi's western tributaries and opened for small boats the river channel below Berhampur, which had been closed since January and the general condition of the whole river was better, though the entrance deteriorated in 1833, during which year and 1834 the channel was kept open, but with difficulty In the flood season of 1832 the entrance of the Jalangi shifted 5 miles to the north and closed early in the dry season, but the next year there was some improvement and with the aid of two hand dredges, a channel for small boats was maintained throughout the season. The Matabhanga in the meanwhile continued to give trouble, closing early owing to the greater volume of the discharge passing into the Pangasi, and a proposal was made to divert the current into a loop taking off the right bank of the Matabhanga above the Pangasi offtake

Work on Nadia rivers temporarily discontinued, 1835

39. Work on the Nadia rivers was stopped in 1835 and the establishment discharged, as it was thought the results obtained were not worth the cost, but in June 1837, Mr May was again appointed Superintendent and found the rivers had deteriorated At the end of the rains the Bhagirathi had three entrances, the best being the uppermost one with a depth of 2½ feet over stiff mud A 3½ feet channel was cut through this and was opened by the flow through to a depth of 10 feet, increasing in width from 18 feet to 250 feet The channel below was kept open with a depth of a little over three feet and in 1839-40, it was even better than in the two preceding years. The entrance during this time was about 13 miles north of Geria The Jalangi entrance was improved from 3½ to 4½ feet in January 1838 The river was kept open till April but in the two following years, it closed early in February and the Matabhanga did the same

1840-1853

40 Mr May was succeeded by Captain Smyth in August 1840 The Bhagirathi which permitted large boat traffic throughout the dry season of 1840-41 gradually became worse in 1841-42 boats of only 2½ feet draft could pass and in 1842 43 it was more obstructed than in the previous five years and there were many complaints With great difficulty a depth of about 3 feet was maintained the following dry season and in 1845-46 a passage was secured for boats of 2 feet draft. The next season the entrance was so unfavourably placed, that it closed in February 1846 and by May the depth had fallen to one foot

41 A new channel from the Ganges about 4½ miles downstream, was cut into the Bhagirathi across a neck 1,500 feet wide, and this rapidly improved, giving 5 to 10 feet of water. The main Ganges channel travelled gradually south-westward, carrying this new entrance downstream and closer to Geria, but the intake gradually deteriorated and in 1852-53 closed as early as November when the entrance was just abreast of Suti.

42. The Jalangi remained in a bad state throughout the period from 1839-47. In 1840-42 it gave a depth of 2′ 9″ at the entrance, but only 1′ feet on shoals lower down The next year it was kept open for traffic till March, but closed early in December the four following seasons. In 1846-47 when the Bhagirathi was bad, the entrance of the Jalangi was deepened, but bars lower down the river were very obstructive and goods had to be conveyed overland, or in canoes In 1850-51 the entrance of the Jalangi had two branches the western one lying open to the Ganges current was easily improved and the river remained throughout the season better than it had ever done. After the rains of 1853 however, two large sandbanks in the Ganges above and below the entrance joined, completely blocking it early in December.

43 Between 1840-41 and 1850 the Matabhanga was never navigable below the Pangasi offtake and for a great part of the time, it had an entrance common with the Jalangi, but in November 1850 the Ganges right bank cut into the Matabhanga lower down and forced a large supply of water into it, the greater part of which, however, was taken away by the Pangasi. In 1852 by the construction of a channel for ten miles below

the Pangasi by artificial banks just wide enough to admit one boat, and with the use of *kodalis*, a passage was maintained for small boats.

44. This history of the Nadia rivers, derived chiefly from Major Lang's Report of 1848, shows that since the records commence, over a century ago, great difficulty has always been experienced during the dry season in maintaining a channel of even two to three feet depth, for the passage of the ordinary traffic boats and this was almost entirely due to unfavourable conditions at the offtakes from the Ganges. As has been stated, the continual changes in positions of the entrances are due to their being prolongations of the river channels through the diara land of the Ganges, which is throughout in a constant state of erosion and reformation, owing to the vagaries of the main stream. In the multiplicity of changes, it is very difficult to trace any regular law of development, but in the case of the Bhagirathi there are certain indications which give promise of results if fully worked out. At present the Bhagirathi takes off from a loop channel (the Faracca channel) of the Ganges which runs along the permanent right bank of the main river for 30 miles from Faracca, 16 miles below Rajmahal, entering the main stream again at Naranpur 4 miles below the Bhagirathi offtake at Biswanathpur. The Faracca channel is fed by three entrances from the main stream, the first at Faracca at the head of the loop, the second and third through the intervening sandbank at Kaliganj, 17 miles down the loop, and at Nurpur close to Suti at the 20th mile.

Indications of a regular law of development of Bhagirathi intake

Faracca channel

45. The two uppermost entrances, Faracca and Kaliganj, have been practically closed for some years, leaving the bed of the Faracca channel dry for the upper 18 or 19 miles of its course. The supply to the lower end of the Faracca channel and so to the Bhagirathi, has consequently been through the Nurpur, or as it is also called, the Mondai channel, and a few years back the main portion of the Ganges stream passed through it. The greater part of the discharge during the dry season flowed off through the lower end of the Faracca channel at Kalitolla or Naraupur, but a portion passed into the Bhagirathi at Biswanathpur. This was, however, considerably restricted owing to the mouth of the Bhagirathi being inclined downstream and its bed being about 20 feet higher than the bed of the Faracca channel. If the lower outlet of the Faracca channel improves, the discharge into the Bhagirathi is naturally reduced, particularly as its inlet forms a backwater. Recently the Nurpur channel has blocked and the Kaliganj entrance opened again.

Upper portion of Faracca channel dry in cold season

Supply to Bhagirathi through Nurpur or Mondai channel

Bed of Bhagirathi 20 feet higher than bed of Faracca channel

46. In 1772 the Bhagirathi intake was due east of Suti. In 1822, as will be seen on map No. 3, the Ganges main channel passed about 3 miles away from Faracca, flowing eastward in a great loop. The Bhagirathi head having shifted 15 miles northward, took off about nine miles due east of Faracca and followed a winding course through the diara into the Nurpur entrance at Suti. A second entrance which existed about 4 miles above the chief one, was monopolised by the Ganges main stream in 1825 and the Bhagirathi then found an off take lower down, and still emerged in the Nurpur intake. The Bhagirathi entrance continued to work gradually, but remarkably regularly downstream, its channel traversing every portion of the intervening diara, but issuing uniformly through the passage at Nurpur. This seemed to form a focus for the gradually shortening channel, till in 1869 the latter merged into the Ganges main channel which carried all the discharge down the main stream, and the intake shortly afterwards was blocked. In 1871 the Chaurasia entrance, five miles lower down, opened and remained the intake of the Bhagirathi till 1882, when the present Kaliganj entrance opened 8 miles upstream. This passage was the main inlet for five years until the Faracca intake at the head of the loop channel which had been open since 1883, commenced to admit an increased discharge. The inlet head worked gradually downstream and with the Kaliganj and Nurpur entrances which opened again subsequently, furnished the supply of the Bhagirathi. The Faracca and Kaliganj entrances gradually became worse, until the whole length of the Faracca loop to below the latter, was generally dry in the cold season. The Ganges main stream passed through the Nurpur entrance in 1914, but the lower outlet of the Faracca channel at Naranpur improved, so that the discharge was carried past the Bhagirathi entrance. As happened in 1870 after the main Ganges channel had encroached on the Nurpur entrance, the latter again suddenly deteriorated last cold season.

General tendency of Bhagirathi channel to Nurpur entrance

Chaurasia entrance extreme southern limit

47. Two points are clearly shown by an examination of the map, (1) the gradual and uniform progression of the Bhagirathi inlet downstream from the upper limit of origin abreast Faracca to the southern limit at the permanent entrance of the river at Geria, as the great Ganges loop gradually worked itself out downstream, and then a reversal again to the upper limit.

(2) The focussing tendency of the Nurpur channel. This was the entrance in Tavernier's time 1666 and again in 1772. Between the latter date and 1820 there are no records, but the Nurpur entrance remained the inlet in spite of continually varying positions of the channel above, for 50 years from 1820 to 1870 when the intake shifted to its extreme southern limit. It was till recently and had been for some years the chief intake channel. This Nurpur channel lies in the bed or diara of the Ganges and there appear to be some peculiar circumstances which prevent its entire obliteration in the ordinary course.

Two points in development of Bhagirathi intake. Gradual progression of intake head downstream and focussing tendency of Nurpur channel

48. It was proposed by the Executive Engineer, Nadia Rivers Division, a few years ago, to make an artificial cut from the Nurpur channel across the intervening point into the Bhagirathi below Geria. This by providing a favourably inclined inlet in the direction where the stream tended to flow, was expected to provide sufficient depth at the entrance and though the initial cost would have been heavy, a great reduction was anticipated in the recurring dredging charges. As the Nurpur channel seems fairly well

Proposed artificial cut from Nurpur channel to Bhagirathi below Geria

fixed and stable, it would have been interesting to have watched the development of the experiment, and it is possible the cut might have delayed the recent closing of the channel.

Present unfavourable period for Bhagirathi owing to straightening of Ganges channel

49. The Ganges in the section between Rajmahal and Rampur Boalia has straightened out its channel and for a period, until it gradually works out another loop, the Bhagirathi intake is under natural conditions, probably likely to receive a restricted supply, as the increased slope of the main stream carries a greater portion of its supply past the inlet and with a straightened channel, there is less chance of a favourable direction of the current of the main stream into the inlet. This applies more particularly to the dry season when the total discharge of the Ganges sinks as low as 30,000 to 40,000 cusecs, which is practically all required for the maintenance of the main channel

River channels proper of Nadia Rivers

50 In the river channels proper of the feeders, changes are incessant, but while in individual portions, alterations are continually taking place, loops being formed, cut through and reformed, so that traces of the old channels in the form of semi-circular jhils or lakes are frequent along the banks, the rivers as a whole have preserved their general characters and directions for a considerable time

Comparison of Bhagirathi with Rennell's survey

51 In map No 2, Rennell's survey of the Nadia district, 1772, is reproduced in red * It will be seen that the only portions of the Bhagirathi channel which have persisted apparently unchanged are the straight sections from Jiaganj to Murshidabad and at Berhampur The permanency of the channel in these places is probably due to the Bhagirathi embankment on the left bank, but between the sections, the Moti jhil is left as a relic of the main channel where a loop in Rennells' survey has been cut through, and below to Plassey, to which place the embankments continue, changes have been considerable. Katwa has apparently always been on the river bank, but between this town and Nadia, the channel has wandered over a large tract, and Agradwip which in Rennell's time was on the left bank, lay on the right bank of the river for years previous to 1913, when the cutting through of the Agradwip loop transferred it again to the left bank His map also shows traces of the old channel, the change from which brought Nadia from the left to the right bank.

Changes in Jalangi since Rennell's time

The Jalangi shows similar changes, but in certain portions, particularly the lower sections between Patkabari and Krishnagar, the formation of the bends have been well preserved and what alterations are exhibited seem very small when allowance is made for slightly incorrect mapping in Rennell's chart As a matter of fact, this section gives the appearance of a river with well formed and established banks in places, probably in stiffer material and so less subject to erosion This is all the more remarkable as since Rennell's survey the Bhairab has opened, entering the Jalangi at Muktiapur above Patkabari

52 Rennell shows the Bhairab as a thread of a channel draining south from the Kulkuli river at Akriganj and following generally and indefinitely the present Banti and Suti Nadis The Kulkuli itself, probably an old Ganges channel, had no definite connection with the main river and was only a flood season spill stream, flowing due east and passing Akriganj and Maricha, it then took the general course of the present Sialmari river south into the Jalangi It was obviously only mapped in roughly by Rennell, probably being regarded as unimportant Since his time the connection between Akriganj and Maricha has been destroyed (probably through the Ganges channel working southward into it), the Sialmari became an independent flood spill stream and the Bhairab found an entrance of its own near Akriganj This, probably by lying open to the Ganges main current at some time, forced a greater discharge into the river with the consequence that the lower reaches opened and a new eastern branch, or the Bhairab proper, developed through country in which Rennell gives no indication of the existence of any stream This seems to have been definitely effected as recently as 1874, developing in the eighties, when it became the real entrance channel of the Jalangi, the old channel from Jalangi having completely silted up and flowing now only in the flood season The Bhairab had in 1914 appropriated the upper course of the Kulkuli and took off the Ganges about 10 miles westward of Akriganj for which length it flows a short distance away from and generally parallel with the main river The old Jalangi channel is at present only a flood spill stream and the entrance is now appropriated by the Matabhanga, as it was between 1840—1850, when both rivers had a common offtake The old Jalangi, being a cross channel with a later flood than the Bhairab, has naturally deteriorated and is unlikely to improve while the Bhairab is a good river, but it may resume its activity with any deterioration of the latter

Opening of new Bhairab river, 1874

Old Jalangi channel may resume its activity

Changes in Matabhanga river

Opening of modern Churni

53 The Matabhanga has changed considerably throughout Below Sibnibas in Rennell's time it continued along the present Ichhamati channel for about twenty miles and the Churni which was a mere nullah, then branched off due westward and passing somewhere just north of Aranghata, trended south-westward into its present channel at Ranaghat. Probably with the greater discharge into the Mathabhanga in the last years of the 18th century, the modern Churni opened out south-westward from Sibnibas through a tract where Rennell shows no stream and then joined the old channel near Ranaghat

54 The channels of all three feeders wind considerably, so much so that Major Hirst regards it as a special abnormality not explicable by the usual processes, but due

* Rennell's maps though wonderfully accurate generally, considering the means and time at his disposal, require considerable manipulation to make them comparable with present maps The only possible method, by reducing them piece-meal, using existing villages situated close together, leaves errors in bearing uncompensated, which have to be distributed through each section, and there still remains the presumption that river courses some distance from the road routes of the surveys were merely sketched in The Bhagirathi certainly and presumably also the Jalangi as shown on Rennell's map, were actually surveyed by Du Gloss

Winding of Nadia rivers channels considered abnormal by Major Hirst

probably to a great extent to the influence of the depression at Nadia postulated by him As a matter of fact with the conditions of soil and discharge prevailing over the delta, all the rivers wind to a greater or less extent, so that this feature has even prompted the naming of streams such as the Atharabanka (eighteen bends) in the 24-Parganas and again in the Khulna district Fergusson who considered the subject specially and endeavoured to adduce fixed laws for the curves of rivers according to their size, apparently did not find any marked abnormality in this respect in the Nadia rivers Throughout the world, this characteristic is noticeable in rivers flowing through alluvial plains and even great rivers such as the Mississippi and Tigris exhibit it to a marked degree, as can be verified on their maps. The question is simply one of the relation between the varying erosive action of the current and the resistance of the soil. A current, even though fully charged with silt, striking an erodible bank at a favourable angle, cuts into it naturally along the portion exposed to attack and a concave bank, or bight, is thus formed with comparatively deep water along its face, the material dislodged is transported downstream until the velocity, being gradually dissipated by the resistance of the bank and by the cross currents and eddies created by the erosion, is insufficient to carry it on and it is dropped, the current is deflected by the direction of the bank and its centrifugal action across to the opposite bank and the slope being lessened and the velocity reduced, deposit takes place over the whole cross section and a bar is thus formed at the crossing This creates a head and the slope being increased, the current then strikes on the opposite bank below the crossing with accelerated velocity and the whole process is thus continued According to the more or less friable nature of the soil, the curves are worked out deeper, tending by the lengthening of the bends and consequent flattening of the general slope to reduce the velocity, until the erosive power of the current is brought into equilibrium with the resistance of the soil. If the soil were perfectly homogeneous and velocity constant, the river would work back on itself in a circular loop, and though under ordinary conditions this does not happen, the bends of two successive loops sometimes cut into each other, or they may be brought so near that only a narrow neck is left separating them During a high flood the water pouring over the neck and falling with a greatly increased slope, owing to the shorter length of channel, into the loop below, cuts back into the neck and if the conditions are favourable a "cut off" is established and the main river channel passes through the new passage With the greatly varying discharge of the Nadia rivers and the very friable nature of the soil, the conditions, where erosion is not restricted by embankments, are very favourable for the development of loops and the process is fully accounted for by ordinary physical agencies A "cut off" when it occurs, is very disturbing to the regimen of the river for some distance above and below it Owing to the sudden increase in slope, scour takes place actively and the river endeavours to re-establish the former conditions approaching equilibrium, by lengthening the bend It consequently happens that other necks in the vicinity of the first "cut off" may be scoured through and a group of successive "cut offs" will occur, straightening the river channel considerably This by increasing the scour throughout might be expected to be beneficial, but the scour is not confined to the bed, and the banks are vigorously attacked till the old conditions are established Furthermore, as the water drains off quicker, the level is reduced, balancing the erosion and in the low water season when the discharge is at a minimum, the depth on the crossings may be even less than before Consequently "cut offs" in a properly conserved river are guarded against as introducing a disturbing factor, the consequences of which are not easily calculable These "cut offs" have been of common occurrence on the Nadia rivers and in the Matabhanga were artificially effected in order to attract the water from the Kumar and Pangasi, as already described A proposal was made in 1831 by Mr. May to increase the slope and shorten the channel of the Jalangi by a number of cuts at the longer loops, but this was never carried out About 6 years ago a natural cut off took place at the Nawapara loop just above the discharged observation station at Banditpur and another cut off is imminent just below Patkabari In the Bhagirathi, "cut offs" have been frequently effected as exemplified in the various semi-circular jhils along its course About 1911 a loop at Nadia was cut through, and in 1913 the river deserted the 14 miles of winding channel eastward of Agradwip and forced a new cut through, a passage afforded by the Patuli khal shortening its course nine miles This was followed almost immediately by the desertion of the Harubhanga loop of 8½ miles at Kaliganj above Katwa, where the Bhagirathi appropriated a small artificial cut and emerged into the Dwarka at Bishnupur effecting another shortening of 6 miles At both these new channels the disturbance is still great, as is shown by violent flurries and eddies • In 1914 shortly after the Harubhanga cut off, the Dadpur loop of 4½ miles was cut through, this being a typical natural cut off, comparable with the Nawapara cut off in the Jalangi The deserted channels in these cases rapidly silt up and within four or five years portions are under cultivation

General development of river channels in alluvial plains

Formation of "Cut off"

Disturbance o regime of river

Cut offs in Bhagirathi

Nadia, Agradwip Harubhanga and Dadpur loops

Bhapta loop threatens Murshidabad railway

56 Erosion has also been active at Bhapta about 8 miles above Dadpur extending a long bend which now threatens to cut into the Eastern Bengal Railway line to Murshidabad In order to save a breach, it has been suggested to cut through the neck of the bend and establish an artificial "cut off" Borings taken along the site of the proposed cut have, however, revealed the existence of a bed of blue clay which is unlikely to scour naturally and sufficiently to provide an adequate channel for the river. It will be noticed that in certain localities, owing to the particularly friable nature of the soil, or other circumstances, the river channel is continuously working out loops and cutting through them. This is particularly noticeable at the two ends of the Katwa reach, which

Unstable regimen in particular localities

in the middle portion is remarkably stable, showing very little alteration since Rennell's time. Between Plassey and Udhanpur at the upper end of the reach, the channel has wandered considerably and there are numerous traces of old courses and beds, and it is here that the Harubhanga loop has recently been cut through. Below Katwa, the Agradwip area for miles is an intricate net work of old channels

Influence of Dwarka and Ajai discharges on Bhagirathi channel at upper and lower end of Katwa reach

57. The extreme instability of the regimen in these places is undoubtedly to a great extent due to the very variable nature of the discharges of the Bhagirathi's tributaries, the Babla, or Dwarka, which enters abreast the Harubhanga loop and the Ajai flowing in at Katwa. These streams bring down their supplies in sudden rushes and this reinforcement of the main current, acting in what is presumably particularly loose soil, sets up active erosion, resulting in the continual reformation of the channel.

General slope of Nadia and Murshidabad districts

58. The general slope of the country covered by the Murshidabad and Nadia districts is towards the south-east, but the slope is very gradual and the area is so interspersed with jhils and marshes and intersected by old courses of rivers, that the general lines of drainage are not easily defined The Bhagirathi with its high banks is the natural boundary of the area on the west and the slope to the south-east of the tract immediately adjacent to the river, is so marked that a practically continuous line of embankment along the left bank from Kulgachi, 18 miles from the entrance, to Plassey, has been necessary to protect important cities such as Murshidabad and Berhampur and other settlements from inundation during the flood season. This slope on the west with the trend from the high right bank of the Ganges, which bounds the area on the north and east, from Lalgola to the old Jalangi entrance, forms a basin in the upper portion of the district and the drainage lines converge to a middle region below Daulat Bazar. Through the middle of this tract the Bhairab now runs in a general southerly direction and the recent opening of the river must naturally have been greatly facilitated by the general trend of drainage, once a satisfactory inlet through the Ganges bank at Akriganj was developed

Basin in upper portion of district

Sialmari river an old channel

59. To the east of the Bhairab, the Sialmari runs through the country in a south-easterly course at an angle to the drainage tendency Being an old spill stream which was well developed in Rennell's time, it has been able to maintain itself, but under the circumstances, is apparently incapable of further development Between the Bhagirathi and Bhairab, the Gobra Nala formerly took any spill from the Bhagirathi such as that through breaches in the embankment which at times allowed as much as 50,000 cusecs to pass for a week at a time This was discharged through the Kalantar, a low lying area of bils and marshes lying east of Beldanga. The Gobra Nala has been beheaded by the railway and new embankment from Jiaganj to Bhagabangola, and it now generally carries only surface and clear water and has consequently become simply a sluggish drain, though 20 to 50 feet deep in places It is called the Bhandardaha Nala at its lower end and chiefly drains across along the line of the Beldanga Amtala district road into the Suti Nadi This latter nullah is a continuation of the Banti Nadi which is a spill of the Bhairab, taking off at Banti east of Daulat Bazar and forms the older and western branch of that river, which is shewn on Rennell's charts It re-enters the Bhairab-Jalangi, at Bali Tungi, at the same point where Rennell shows the confluence, in the middle of a double right angled loop which has very faithfully preserved its form since his time The old Bhairab branch, or Banti Nadi flows east from the head of the Suti Nadi and under the name of Kumar Nadi, enters the main branch higher up and immediately at its confluence with the Jalangi near Muktiapur

Gobra Nala

Suti and Banti Nadis, old Bhairab branch

Kalantar area

60 The area south of Beldanga between the Bhagirathi and Jalangi already mentioned as the Kalantar, forms a natural basin comprising large marshes such as the Pat and Salmari bils now practically cut off from any spill This district with no definite drainage, forms in the rainy season a huge shallow lake in which a peculiar long stemmed rice is grown, and dotted here and there with villages built on mounds

Slope becomes more decidedly to the south-east between Jalangi and Matabhanga

61 Between the Bhairab Jalangi and Matabhanga, the country is intersected by innumerable old river courses, such as the old Bhairab channel, and bils, trending in every direction, but the general slope becomes more decidedly south-easterly and cuts across the Matabhanga at a considerable angle In consequence of this, the greater part of the Matabhanga spill is carried away to the south-east by the Kumar and Ichhamati distributaries The slope is so pronounced that, as already mentioned, a successful attempt at closing the Kumar offtake in 1820 merely resulted in the opening of another outlet lower down, and, as will be seen from the history already given, ever since the beginning of last century, the difficulty in keeping the Matabhanga open has been due to the fact that its Jessore distributaries took away from three-fourths to five-sixths of its spill supply In spite of the various attempts to divert it, they, at the present time, are estimated to draw off seven-tenths of its discharge before it reaches the Hooghly

62 This drainage tendency to the south-east from the Matabhanga has, therefore, been in marked evidence for over a hundred years and the opening of the modern Churni channel south-west from Sibnibas at about the end of the 18th century must, most probably, have been due to abnormal causes such as a considerable afflux which burst its way into convenient low-lying country and developed a channel, which, once formed, has continued to provide a waterway

Embankments in Nadia area

63 The only regular embankments on the Nadia rivers are the protective system along the left bank of the Bhagirathi, known in the upper part as the Laltakuri embankment and the Kachikata embankment for a short distance on the left bank of the

Matabhanga. The Laltakuri system was connected to the Ganges embankment running along its right bank, from Chintamoni above Lalgola to Akriganj, by a cross connection at the head, between Kulgachi and Chintamoni, and another cross enbankment from Jiaganj to Bhagabangola has recently been constructed, thus enclosing a rough quadrilateral between the Bhagirathi and an old bed of the Ganges shown on Rennell's chart

Laltakuri embankment

Ganges embankment

64. The Laltakuri embankment though preventing the natural spill of the Bhagirathi, so that Mr. Wickes, Superintending Engineer in 1885, remarked, "I believe however that the man who embanked the Bhagirathi would, if in Egypt, have embanked out the Nile waters" has been frequently breached during high floods High floods have on many occasions inundated the Nadia District* In 1801 a flood of great severity occurred, followed by another very sêvere flood in 1823, which is supposed to have lasted nearly two months In 1838 there was another heavy inundation and in 1856 a very severe flood, the embankment breaching at Laltakuri Breaches again occurred in 1867 and 1870 when the flooding was fairly great and again in 1871 there was a high flood of great duration The embankment was breached again at Laltakuri and it was calculated that the average discharge through the breach was 40,000 cusecs Three hundred and twenty-one square miles of the Murshidabad District were flooded, of which 285 square miles were situated south of the Jiaganj-Bhagabangola Road, which at that time had not been embanked. The flood joined the Jalangi flood and passing north of Krishnagar, amalgamated with the Mathabhanga spill and breached the Eastern Bengal Railway embankment. The inundation lasted six or seven weeks

Laltakuri embankment prevents natural spill and is subject to heavy breaches

Breaches in 1801, 1823, 1831, 1856 1867 and 1870

Great flood of 1871

65 A minor breach occurred in 1874 and a heavy flood which breached the Murshidabad embankment in 17 places, though not at Laltakuri, caused extensive inundation in 1879 Six years later in 1885, one of the heaviest floods on record occurred The embankment burst again near Laltakuri on the 23rd August and the gap widened from 200 to 800 feet in one night and eventually reached a width of nearly half a mile The discharge through the breach was presumed to have been about 50,000 cusecs for three weeks from 24th August to 14th September By the 25th September, the discharge fell to 14,000 cusecs and rapidly decreased The flood poured south-east over the country to the east of the Bhagirathi along the Gobra Nala It filled up the Kalantar area, joined the Jalangi spill and then united with a heavy flood in the Matabhanga which breached the Eastern Bengal Railway near Bagula and the Bengal Central Railway between Gopalnagar and Bangaon. The area inundated between the Bhagirathi and Eastern Bengal Railway was 1,000 square miles, between the Eastern Bengal and Bengal Central Railway 600 square miles and below the latter about 1,200 square miles This flood lasted about a month

Breaches in 1874 and 1879

Great Breach and flood in 1885

Discharge of 50,000 cusecs through breach for three weeks

66 In 1889, when the Berhampur gauge recorded the highest reading so far registered, the embankment was again breached in two places and with a still higher reading of the gauge in 1890, another breach occurred at Laltakuri, though the floods in these years were moderate Since then there have been no severe floods, though the embankment was breached as recently as 1907 After the flood of 1874, Mr Wickes had drawn attention to the difficulty of maintaining the Murshidabad embankment during high floods on account of the extremely treacherous nature of the soil He proposed that the road from Jiaganj to Bhagabangola should be embanked to serve as a second line of defence, should the river embankment burst, as it usually did, at Laltakuri, subsequently it should be considered whether the upper portion of the river embankment above Jiaganj need be maintained There was considerable discussion over this matter extending over a long period, during which other high inundations such as that in 1885 occurred, and various other proposals were put forward, such as the entire abandonment of all embankments which, though the most popular scheme, was given up on account of the uncertainty as to the amount of compensation the Government might be called upon to pay A third proposal was to construct a retired line along the Dewan Serai Road.

Breaches in 1889, 1890 and 1907

Treacherous nature of soil at Laltakuri

Wickes' proposal to embank Bhagabangola road and abandon upper Laltakuri embankments

Proposal to abandon all embankments

Proposal to embank the Dewan Serai Road

67. Finally, it was decided to construct the Jiaganj-Bhagabangola embankment and to abandon the Laltakuri Bund on the Bhagirathi for 20 miles from its upper end at Kulgachi to near Jiaganj, throwing the quadrilateral area mentioned, open to spill from the river, and the activity of the Bhagirathi is evidenced by the fact that this district is now being raised at an estimated rate in places of about 3 inches in a year

Abandonment of 20 miles of Laltakuri embankment

68. An important circumstance in connection with the Bhagirathi breaches does not appear so far to have attracted attention If the curve of Berhampur levels on plate No 1, or the corresponding statement C, is examined, it will be seen that in the years 1867, 1871 and 1885, when the heaviest breaches occurred, and also in 1907, the low-water level in the dry season previous, shows a sudden and considerable rise. Now the low flood level at Berhampur, relatively for two consecutive years, depends on two factors, the percolation supply and that through the entrance The former may be regarded as fairly constant, while the latter varies from nil when the entrance is blocked, to a maximum quantity when it is well open The Chaurasia entrance opened in 1871 The Faracca and Kaliganj entrances were apparently well open in 1885 and presumably there was a good flow through in 1867 to raise the low-stage level 2' 3" higher than in the previous year, and again, though not to the same extent in 1907. Owing to the height of the low-stage level in these years, the range to the high-stage, though, bringing the flood to or near the top of the embankment, is only about, or even less than the average range for the decennial period. In the remaining years 1870, 1874, 1879, 1889 and 1890 when the floods through breaches were moderate, the range is considerably above the average. In 1889

Breaches of embankment in years of sudden rise of low-water level

* Wickes' report of 1885 and O C Lees' report, 1895

and 1890 the river levels reached the maximum recorded heights to that time and yet the breaches were comparatively unimportant as the entrance was apparently in a bad state. The heaviest floods have, therefore, occurred when the Bhagirathi entrance in the dry season opened and was followed by a high, or even a moderately high flood in the Ganges, giving a strong rush through the river With the entrance in a deteriorated state, as it has been for many years now, no heavy floods can be expected, but as the phase passes, should a new entrance develop at a time when the Ganges flood is fairly high, the embankments will again be subjected to a severe strain, though the removal of the weakest section above Jiaganj where a large spill area has been thrown open, will minimise the risk of further breaches

No breaches anticipated in present state of Bhagirathi entrance

69. In addition to the main embankments, there are numerous zemindari bunds of about 3 feet in height, protecting land at threatened points from inundation, and preventing spill from disseminating freely, and the various district roads have a further restricting effect In addition to the main protective embankment on the left bank, the Bhagirathi has a double defence against heavy spill in the railway embankment from Plassey through Murshidabad and Jiaganj to Bhagabangola and to its terminus at Lalgola Below Plassey the railway runs south-east midway through the tract between the two rivers and crosses the Jalangi at Krishnagar Heavy spill from the Bhagirathi is, therefore, prevented at the present time, except in the upper portion where, as already mentioned, the embankment has been abandoned Along the Bhairab-Jalangi and Matabhanga, there are reaches where the rivers have a certain amount of local spill and plans have been prepared as famine relief measures to utilise this spill to fill up low-lying land or bils at various points, among these being the Choa project to reclaim the low area between the two branches of the Bhairab above Amtala.

Railway embankments

Spill from Nadia Rivers

Reclamation of low lands

Choa project

70 At the present time the Bistupore bil to the east of Berhampur is being reclaimed by carrying spill from the Bhagirathi into it through a drainage channel, which however, has itself to be continually kept clear of silt deposits settling in it. Major Hirst has laid some stress on methods of reclamation of low-lying areas and draws attention to the procedure followed by Mr Hennessy Mr Addams-Williams points out that there are many cases in nature where a similar process has been carried on by the rivers. The tendency is, however, for the connecting channels to throw down a bar at their offtakes and to sever the bils from the rivers The objection to such methods is that the bils are filled only once in the flood season and the process of silting must, therefore, be necessarily slow a more rapid process would be to pass a continuous stream through the low lands by excavating an exit channel, which would be regulated so that when the rivers begin to fall, the exit can be closed and the bil emptied back into the river to flush the feeding channel The water passed on by the exit channel in such cases containing very little silt improves the river below by scour, as has been the case in the Khulna district

Reclamation of Bistupur bil

Methods of reclamation

71 Major Hirst mentions that the fact that the Kol cultivators have been using Italian bonificazione methods of reclamation probably for centuries has apparently not been noticed Mr Addams-Williams states that Mr G C Maconchy's notes for the Irrigation Commission contain full details of these operations and that in all drainage projects in these districts, the question of bringing silt-laden water on the land is being considered

72 The past history of the rivers and the general condition of the Nadia area having been considered it is now necessary to proceed to an examination of present conditions of these feeders of the Hooghly

CHAPTER III.

Physical conditions prevalent in the Nadia Rivers and Tributaries.

Bhagirathi an independent river as well as a spill stream

1. The Bhagirathi is the most important of the feeder rivers and is distinct from the others in that it is not merely a spill channel, but carries an independent supply, thus combining the functions of a true river in its lower portion with those of a spill stream. Through its tributaries entering from the west, the Ajai, Mor and Brahmini forming the Babla or Dwarka, Banslai river and Jumjumkhali Khal, it drains a watershed of its own, 6,700 square miles in area, covering a large portion of the Birbhum district and high lands in the Santal Parganas, with an average rainfall of about 53 inches.*

Length of Bhagirathi

2. Excluding the Faracca channel which, as stated above, is not actually a portion of the Bhagirathi, but a "sota" of the Ganges 30 miles in length, with the Kaliganj and Nurpur entrances at the 17th and 20th mile from its head, the length of the Bhagirathi from its entrance at Biswanatnpur to Nadia is now about 141 miles Previous to 1913 when the Agradwip, Harubhanga and Dadpur "cut offs" shortened the river channel 20 miles, the total length of the river was 161 miles, so that the present length of the river channel cannot be regarded as in any way constant For administrative purposes, it is divided into two sections the upper Bhagirathi from the entrance to Dadpur, 77 miles, and the Lower Bhagirathi from Dadpur to Nadia, 64 miles, in this latter section the more important tributaries, the Ajai and Dwarka, enter.

Entrance of Bhagirathi

3. The entrance at the present time trends south-east from Bhangabari about 3 miles from the mouth, being inclined down stream to the main current of the Ganges. The

*Map No 2

bed of the Bhagirathi at the entrance, which at the end of April 1913 was 54′ 9″ above Kidderpore Old Dock Sill—which I shall refer to hereafter as datum,—and about 20 feet higher than the bed of the Faracca channel, appears to have got progressively higher since, being 55′ 6″ at the end of October 1914, 57′ 6″ at the end of October 1915, and this last dry season, 1918, it was 62′ 9″ above datum. The Ganges level at the mouth falls at its lowest stage to about 50 feet above datum, but this low stage level is subject to considerable variation, having fluctuated in the past four years from approximately 51 feet in 1914 to 54 feet in 1915. It will be seen, therefore, that in a very bad phase of the Bhagirathi, such as we are now experiencing and with a low level of the Ganges of even about 52′ 6″, as in the past season, there would, at the low stage, be a dry sand 10 feet high, blocking the entrance. These conditions are admittedly bad and with an abnormally low Ganges level, they may be worse, but this may be expected from the unfavourable position of the offtake and in the light of the past history of the river, it would appear that we are simply approaching, or have reached the culmination of a bad period.

Bed level at entrance recently getting progressively higher

Kidderpore Old Dock Sill datum

Ganges level at entrance

Dry sand at entrance

4. With a bed level from 55 to 63 feet at the entrance, at the end of the flood season, it will be seen that as the Ganges level falls, the depth over the bar is reduced until the dry sand emerges, stretching across the mouth and this would prevent any further influx into the Bhagirathi, if dredging or scraping operations failed to provide a small gutter through the sand. Usually there is sufficient depth at the entrance to the middle of October, though in 1913 only 3 feet was available at the beginning of that month, but with the fall of the level, the entrance is usually practically dry by the end of December and very little discharge, if any, then finds its way into the river and this is generally cut off later. The entrance which a few years ago had two or three shallow pools, is at the present time blocked by a practically continuous shoal from the mouth to Jangipur, 8 miles down stream, in which length there is only one comparatively deep pool at Alampur at the Bhangabari, or first bend. There was a clay bar at the entrance or Momintola shoal and from the mouth, the Lalkhandiar shoal along the first reach of the river is also founded on clay. The channel of the river exhibits the usual characteristics, having comparatively deep pools in the bights, or bends, separated by shoals at the crossings, or in the straight reaches, where the energy of the current instead of being concentrated on the concave bank is dissipated over the whole cross section. In the year 1916-17, there were 58 shoals, 43 being in the upper and 15 in the lower section of the river.

Stoppage of flow into Bhagirathi as Ganges level falls

Geria Momintola and Lalkhandiar shoals

River channel exhibits usual characteristics

5. Records of the varying river level are kept at Geria and various other places and continuous gauge curves for Berhampur since 1861 and for Jangipur and Katwa since 1890 are shown graphically on plate No. 1, the levels all having been reduced to the common datum, Kidderpore Old Dock Sill, 7·759 feet below G. T. S. mean sea-level, for comparison and easy reference. An analysis of these records shows that the water level at Geria which has an average lowest stage of 54′ 1″ above datum in the dry season when the level is usually dead owing to the entrance being blocked, begins to rise in correspondence with the Ganges level, usually early in June, and generally by the latter end of the month, the river has a mean level of 60 feet above datum. Usually by the middle of July, the level has risen to 70 feet and ordinary boat traffic can be established. The level at Geria reaches its mean maximum height of 79′ 9½″ above datum about the end of August, giving a total mean range from the low stage of nearly 26 feet, and the subsidiary freshet in the Ganges usually keeps the level high till the middle of September. By the first week of October, the mean level has usually fallen to 70 feet above datum and by the end of November, it has generally returned to the 60 feet stage. These mean conditions do not correspond with any particular years and there are naturally considerable variations, due to the irregularity of the Ganges flood, both as regards duration and height, which are influenced by the general conditions of rainfall over the wide drainage basin, particularly in Bihar, whence the immediate supply to the river below Rajmahal is augmented by freshets from the Gandak, Sone, Kosi and Mahananda rivers.

Records of river level at Geria, Jangipur Berhampur and Katwa

Usual stages of river

6. The year 1918 has been an exceptional year of late freshet and owing to very scanty rainfall in July, the river levels have been abnormally low. In the Jalangi and Bhagirathi up till the 9th August, there was not sufficient depth over the shoals for a vessel of 5 feet draft to pass through. Even at Katwa on the 5th August, the level was as much as 7 feet lower than in the worst year since the records are given from 1890.

1918 abnormal year

7. The total quantity of flood discharge in the Ganges depends on the two factors of duration and height, and a high flood does not necessarily connote a prolonged one. For instance a small freshet from the Kosi or Gandak, due to opportune precipitation when the Ganges level was naturally near its culmination, would raise the maximum height at Rajmahal, whereas had the same freshet occurred earlier, or later, though the quantity of discharge would have been identical, the same level would not be reached. As in the Mississippi and other rivers, the highest floods therefore occur when the maximum floods of the main river and some of its tributaries synchronize, it being extremely improbable at the same time, that the absolutely maximum conditions of discharge can ever be reached, when the main river and all its tributaries are in high flood simultaneously.

Duration and height of Ganges flood variable

Highest floods when tributaries and main stream are in flood simultaneously

8. It might be anticipated that with a mean range of 26 feet from low to high stage at the entrance of the Bhagirathi, there would always at the height of the floods, be a fair depth, even over a 10 feet dry sand, but there are circumstances which modify the available depth. Unless the mouth is favourably situated for scour and particularly with back water conditions of the intake as at present, large masses of sand are apparently

Conditions at entrance

carried into the mouth of the Bhagirathi as the Ganges rises, so that the bed is raised together with the water level, though not to the same extent. In other words, the depth of water to be anticipated at any time is not necessarily the depth before the rise, plus the rise at the particular stage, and in the same way when the river level falls, the sand which has been deposited is, to a greater or less extent, scoured away again. The conditions are so uncertain, that in the past few years it was not considered advisable for a vessel of 6 feet draft to attempt the passage until the gauge height at Geria was 66 feet above zero, or 73′ 9″ above datum, so allowing for a rise in the Ganges of about 21 feet, while the bed is now 10 feet above the low stage level at the entrance. The available depth at the maximum stage with the entrance as now in bad condition, is only from 14 to 16 feet. This small depth at the height of the flood season is not unprecedented, as in 1851 there was a maximum depth of only 12 feet, and in 1853 only 14′ 6″. With a favourably inclined intake set fair to the current of the Ganges, the bed at the entrance instead of rising may scour during the flood, as in 1847 when the depth increased from 6 inches only in the dry season to 40 feet in the flood with a rise at the gauge of 28 feet 7 inches.

Small depth at entrance not unprecedented

9. This is a local action which might be expected under the circumstance, in the same way that when the entrance is unfavourably placed, the Ganges simply spills over into it, owing to its raised level and the velocity being considerably reduced, deposit takes place at a time when the river is carrying a greater proportion of silt and sand.

10. In 1913 the maximum depth at the actual entrance was 19 feet and that, only for a week in the middle of August when the river level rose suddenly 5 feet. In 1914 the maximum depth at the entrance increased from 18 feet at the end of July to 24 feet in the middle of August, and over the Lalkhandiar shoal the depth improved from 16 to 21 feet with a rise of stage of 3 feet. A week later the depth at the entrance fell to 13 feet, or 9 feet, with a fall of stage of only 2 feet. In the middle of August 1915, there was only 16 feet depth at the entrance and 12 feet over the Lalkhandiar shoal with the same stage level as in 1914, when the depths were 24 and 21 feet respectively. The maximum depths were 18 and 15 feet on the two shoals early in September. The following year 1916 the depth at the entrance was 19 feet and over the Lalkhandiar shoal 14 feet with the same stage level as in 1915, and a week later the depth on both shoals fell 4 feet with a fall in river level of 2 feet.

General rule regarding raising of bed at shoals on rising stage

11. In the ordinary way throughout the river, the raising of the bed to a certain extent at the shoals on a rising stage, appears to conform with hydraulic laws as observed on the Mississippi and other rivers. During the dry season when the level is low, the slope of the river is greater over the shoals than in the pools, but as the river rises, the slope over the pools is increased and that over the shoals lowered, until towards high flood the difference is eliminated and the river channel has a fairly constant slope, or under certain conditions the variations are even reversed, the slope being now greater over the pools than over the shoals. Now as the slope over the pools where the hydraulic depth is greater, increases, the tendency would be for the river to deepen the pools on the rising stage and raise the shoals where the slope is depressed, until the effect of the greater hydraulic depth counterbalanced the effect of reduced slope, giving a greater velocity in the latter case, and the reverse process would ensue on the following stage. These effects on the bed of the river will be masked to a great extent by the raising of the surface level in the first and fall of that level in the second stage, so that the actual depth of water available may be greater, even though the bed has risen.

Illustration of rule on plate No 3

12. The general rule cannot of course be regarded as an invariable law and is subject to modification, particularly at the entrances of spill rivers according to local conditions. It is, however, well illustrated in the case of the Bhagirathi on plate No 3 showing the longitudinal section along the first, or Geria reach of the river, taken before and after the first freshet came into the river. The bed as surveyed on 1st December 1917, is shown in a full line and as the water level of the Ganges had then fallen below the bed at the entrance, there would have been no flow through and so very little change till the Ganges had again risen sufficiently to spill into it. On the 1st July 1918, the Ganges level had risen 4 feet above the bed at the entrance and the longitudinal section taken, is shown by a dotted line. It will be noticed that the shoals have risen uniformly about 4 feet, and on the other hand, where there was deeper water or pools, the bed level has fallen 3 feet and at the Jangipur pool even as much as 7 feet, though the area scoured is not comparable in extent with the filling in. Throughout the river channel generally, the shoals apparently rise on the rising stage, so that it is very seldom that depths even equal to the maximum rise of stage of about 25 feet are obtainable at high flood level on the bars.

Percolation supply

Not derived from Ganges

13. While the entrance is entirely closed by sand, preventing any influx from the Ganges, the Bhagirathi lower down will be carrying a stream which appears to increase progressively. This supply has generally been ascribed, and can only be due, to percolation of subsoil water through the bed and banks of the river. The source of the percolation supply is usually attributed to the Ganges, but there are difficulties in accepting this view. It will be noticed that at a low stage, in the dry season with a sand blocking the mouth, the level of water in the Bhagirathi is considerably higher than in the Ganges, to the extent of four to five feet and even more, and this water percolates through the sand at the entrance draining the Bhagirathi into the Faracca channel. The flow of water is then outwards and if a channel was cut, the water in the upper reach of the river would be emptied into the Ganges and at times a bund has to be built across the entrance of the Bhagirathi to prevent this. The percolation supply cannot, therefore, be derived from the Ganges anywhere in the vicinity, and from the conditions, it

seems improbable that any infiltration through the banks, a long distance above the Bhagirathi, flowing at a flatter slope than the main stream, furnishes the supply. Nor does there seem any need to ascribe the supply to anything but rainfall absorbed in the soil of the higher country to the west of the Bhagirathi, augmented to a certain extent by seepage into the adjacent regions through the banks of the river when the level is high. In a country where the soil is fairly porous, a considerable percentage of the precipitation, depending on the nature and covering of the ground, is absorbed and forms a great underground reservoir. This moves to lower levels in conformation with hydraulic laws, the velocity varying in direct proportion to the first power of the slope of the underground water table.

Percolation supply derived from rainfall absorbed in ground

14. When the river level is lower than and intersects the water table therefore, the subsoil water seeps through the banks and bed and gives a constant stream. This is a common phenomenon in rivers with a low stage all over the world. In the Nadia rivers, the effect of percolation has naturally been noticed for a considerable time. Major Lang in 1853 stated "It happens on these rivers that although their entrances may be entirely dry, a running stream, the effect of percolation and supplied by springs in their beds, will be found a short distance below their mouths, which increases in volume throughout their courses."

Lang's statement.

15. Major Hirst gives certain figures for January 1915 showing that while there was a back flow into the Ganges of 37 cusecs at Geria, there was a stream of 256 cusecs at Berhampur increasing to 596 cusecs at Katwa owing to discharges from the Dwarka and Ajai (which themselves may have been to some extent due to percolation). He also gives figures showing that the level of sub-soil water in the Murshidabad district for the years 1897 to 1902, was lower than the river surface in September and higher in April, except in 1898 when the subsoil figure is probably an error.

Discharge figures showing effect of percolation in 1915

Levels of sub-soil water and river surface

16. The percolation supply in the Nadia rivers is not considerable and appears to average between four and six hundred cusecs in the lower portions of each of the three rivers, as will be seen in the discharge results for the dry season months in statements G, H and I, the figures given by the ordinary method being taken in the driest month for each river, when the percolation supply is not supplemented by any supply from the Ganges, or rainfall.* In the Bhagirathi, it probably never exceeds 800 cusecs at Katwa. This discharge of 800 cusecs would represent a total quantity of about 10,600 million cubic feet for the dry season from January to June and taking the quantity absorbed by the soil as one-tenth (though there is no certainty about this proportion) of the average precipitation of about 50 inches, the total percolation discharge would be stored in only 540 square miles and this takes no consideration of the quantity of river water which would have filtered through the bank when the river level was high. Of course it must be remembered that the percolation must actually be greater than the visible discharge, as immediately it appears on the surface, it is exposed to the sun and evaporation takes place which amounts to as much as three-eighths of an inch a day during the hot months before the monsoon. This evaporation from a channel, 100 miles in length, with an average width of 400 feet would amount to 80 cubic feet a second.

Percolation supply in Nadia rivers inconsiderable

Total quantity of percolation discharge derivable from 540 square miles of saturated country

Effect of evaporation

17. Leonard on his report of 1865 gave a rough estimate of 20,000 cusecs for the percolation discharge 30 miles above Calcutta. This being in the tidal area where the discharge calculation is complicated by tidal conditions, has apparently been largely over-estimated and it is not likely that under the conditions, any reliable results could be obtained by a rough measurement as Leonard admits his to have been.

Leonard's estimate probably largely excessive

18. The next source of independent supply to be considered is the discharge from the western tributaries of the Bhagirathi.

19. The Singhia Nadi draining the Rajmahal hills falls into the Faracca channel and is, therefore, not actually a tributary of the Bhagirathi, the first affluent of the river being the Banslai entering below the first bend just above Jangipur. The Banslai rises on the western side on the Sontal Parganas near Sarmi and flows eastward through a hilly region. It spills in low-lying country before reaching the Bhagirathi and this serves to regulate its discharge. The river is usually dry from December to May, owing to absence of rain, but the run off in its catchment being rapid, it carries a discharge into the Bhagirathi with any early rainfall and the first rise at Jangipur and Berhampur is, therefore, usually due to influx from the Banslai. Owing to the high rate of run off in its upper reaches, the river, as in the case of all these western tributaries, floods rapidly during heavy rainfall and subsides as quickly. The discharge consequently is very variable, as will be seen in statement J, being generally, however, below 10,000 cusecs. The maximum discharge into the Bhagirathi is probably that registered in October 1916 and in August 1917, being about 25,000 cusecs, but the actual discharge of the river in the upper reaches before it commenced to spill was greater and probably reached about 40,000 cusecs. The extreme variability of the discharge is shown by the observations taken in September and October 1916 and 1917. The discharge of the Banslai rose from 239 cusecs on the 15th September 1916 to 22,823 cusecs on the 22nd September and fell from 35,970 cusecs on the 3rd October to 310 cusecs on the 30th of that month. In September 1917 the discharge was 60 cusecs on the 1st and 9,851 cusecs on the 21st and the maximum and minimum discharges in October were 10,068 on the 7th and 258 on the 26th.

Singhia Nadi

Banslai

Discharge of Banslai

20. The next tributary of the Bhagirathi is the Jumjumkhali nullah entering just below Berhampur. This drains the Telkar bil to the westward and takes some of the spill

Jumjumkhali Nullah

---

* The percolation supply is probably largest at the beginning of the dry season while the soil is sodden and the level of water in the bills is high. As the soil dries during the hot months, the percolation supply would be gradually reduced till in June it would be practically nil.

Heading back in Jumjumkhali nullah

from the Dwarka and Mor rivers; at times it carries a considerable discharge into the Bhagirathi, the mean inflow measured in October 1915 being 28,000 cusecs with a maximum discharge of 45,290 cusecs. At other times when the Bhagirathi level is high, the water backs up into the Jumjumkhali nullah and there is an actual flow upwards, this being nearly 400 cusecs in October 1916. This water later on, when the Bhagirathi level falls, pours back into the river.

Dwarka or Babla river

Brahmini and Mor rivers

Maurakhi, Kana and Kaya nadis Salko river

21. The Dwarka, or Babla as it is also called, falls into the Bhagirathi at Bishnupur just above the Dattabati observation station With the abandonment of the Harubhanga loop in 1913, the Bhagirathi appropriated the lower portion of the Dwarka channel which has been widened to accommodate its greater discharge. The Dwarka is formed by the Brahmini and Dwarka rivers which take their rise in the hilly country east and north of Dumka and combine near Sherpur, below which place they are joined by the river Mor. This river rises east of Deoghur, flows down westward of Dumka and then widens considerably. After crossing the Ondal-Sainthia line of the East Indian Railway at Sainthia, the river spills southward into various channels such as the Maurakhi, Kana and Kaya nadis, the latter being a continuation of the Salko river an intermediate stream between the Mor and Ajai rivers, rising north of Raniganj These streams when in flood, spill into the low-lying Hejol area east of Kandi, which acts as a reservoir, and then drain into the Dwarka.

Hejol area spilling ground

22. When the Bhagirathi level is high, the supply cannot be emptied quickly enough into that river and the water is headed back through the Dwarka and inundates the Hejol, flowing out again as the Bhagirathi level falls This spilling ground, therefore, receives a considerable amount of deposit and the Hejol area is being gradually silted up.*

Discharges

23. The Dwarka when in flood carries a fairly considerable discharge into the Bhagirathi and though the greatest discharge measured since 1915, as shown in statement J, was 39,493 cusecs in October 1916, if the observation had been taken a few days earlier when its tributaries were in full flood, the discharge would probably have been found to have been very much greater. On the 3rd October of that year during abnormal floods, the Brahmini was discharging a maximum of 24,494 cusecs and on the same day the Mor was carrying as much as 110,830 cusecs A large percentage of this spilled, but with the discharges from the Kaya nadi and other khals, a considerably greater quantity than 40,000 cusecs must have entered the Bhagirathi. The Dwarka and its tributaries rise rapidly in flood and in the case of the Brahmini, the discharge rose from 166 cusecs on the 20th September 1916 to 15,495 cusecs two days later The discharge of the Mor rose from 1,137 cusecs on the 15th September to 57,504 cusecs on the 22nd September.

24 In October the minimum and maximum discharges of the Brahmini were 32 and 24,494 cusecs, and of the Mor 969 and 110,830 cusecs.

25 The minimum and maximum discharges of the Mor and Brahmini were 1,125 and 44,880 cusecs and 313 and 16,126 cusecs respectively, in September 1917 and 2,106 and 82,896 cusecs and 258 and 10,068 cusecs respectively, in October 1917

Colour of Babla water

26. The Dwarka, or Babla, flood water has a characteristic red colour, even more so than the Ajai and the first appearance of the freshet in the Hooghly is generally indicated by the highly tinged discharge from this river, the Ganges flood having only the ordinary muddy colour

Ajai river

27 The Ajai river has its source near Sarwan west of Deoghur It runs down through hilly country and in its middle reaches, the slope ranges from 4 to 8 feet per mile It receives the Hingola river as a tributary, on its left bank just below the Pandaveswar Bridge of the Ondal-Sainthia line, and the Tumni Khal on the right bank lower down. A third tributary, the Kunur river, enters on the right bank near Mangalkot, some distance below the crossing of the East Indian Railway loop line It subsequently flows through a low valley, entering the Bhagirathi at Katwa The right bank is protected by embankments for a considerable length between the two railway lines and embankments exist for a short distance on the left bank above Mangalkot

Ajai discharge characteristics

28. The Ajai is a torrential stream and as in the case of Bansloi and Dwarka, floods quickly. 'It is practically dry till May and then commences to bring down a discharge with early rainfall over its catchment Its actual discharge into the Bhagirathi is very variable and is largely influenced by the level of the latter river which, if high, heads back the supply, as in the case of the Dwarka The largest discharge actually measured in the past three years was 32,254 cusecs in October 1917, but this has probably been largely exceeded at other times, particularly in September 1916, when the record flood for half a century occurred on the river, but unfortunately no observations were taken for the discharge into the Bhagirathi at that time The rate of discharge at any time in the lower reaches of the Ajai, as with all spill rivers of this class, is only a fraction of the discharge in the upper reaches before the river commences to spill the result of the overflow of the river into the country on either side, is to lengthen the duration of the flood and so, through the total quantity may eventually be discharged, the actual rate of discharge is reduced.

Rate of discharge of spill rivers of Ajai class reduced in lower reaches

Ajai record flood of September 1916

29 As illustrating the characteristics of the Ajai, a description from the Superintending Engineer's report may be given of the record flood of September 1916 Owing to a storm which passed over the country at the end of that month, the rainfall over the Ajai catchment area was exceptionally heavy, giving an average of about 11 inches for three days, representing a total quantity of about 1,640 million cubic yards over the basin.

Percentage of "run off"

30. The total discharge at Satkahona which is situated on the river about midway between the two railway lines and near Ilambazar, was calculated to be 1,082 million cubic

* I am indebted to Mr J E Monk, Dy Chief Engineer, E I Ry, for these and many useful items of information regarding the Hejol and other areas, obtained in his personal reconnaissance for the proposed cross railway connection from Kandi to Bhairamara

yards, giving a run off of about 66 per cent * The gauge at Satkahona rose from 3′-6″ at 6 A. M. on the 22nd September to the record height of 22′-8″ at noon on the 23rd and subsided to 13′ 6″ at 6 A. M. on the 24th The maximum discharge at Satkahona was calculated to be 256,529 cusecs The river spilled over the left bank into the Hingola and a breach occurred at the bridge over that river on the Ondal-Sainthia line The Ajai also flooded the country to its south through breaches in the right bank embankments and through the Tumni Khal and Kunur river This spill together with that lower down, acted as a reservoir, reducing the rate of discharge in the lower reaches and into the Bhagirathi, but even then the level was raised sufficiently to flood the town of Katwa

Maximum discharge

31. The influence of the railway embankments of the Ondal-Sainthia and Loop lines which run across at right angles to the line of flow, was apparent, in causing pooling above the bridges The waterways in the bridges on the railway lines are presumed to be insufficient and this would probably be no disadvantage if the embankments were strong enough to make breaches impossible, as the reservoir action would regulate the discharge and prevent destructive flooding in the lower reaches where the supply cannot be discharged quickly enough into the Bhagirathi However, with considerable pooling above the line, if a breach occurs, a flood wave is caused, which does more damage than a gradual rise. Owing to the obstruction of the Bhedia bridge on the loop line, the bed of the river at that place was apparently raised and when fairly heavy rainfall occurred later on the 3rd October, another flood occurred.

Influence of railway lines on Ajai flood

32. The flood levels of the Ajai since 1857 show a tendency to be gradually raised and a comparison of sections taken in 1883 and 1916 at Betta and Basudah show a slight reduction, indicating that the bed of the river is gradually rising.

Raising of flood levels and bed of Ajai river

33. A serious flood also occurred in the river in 1913 when, however, the discharge at Satkahona was about 180,000 cusecs as compared with 256,529 cusecs of the 1916 flood

Flood of September 1913

34 The maximum discharge of all the tributaries of the Bhagirathi with abnormally high floods in all the rivers would, therefore, be about 450,000 cusecs This of course is a condition which is never likely to be realised, as maximum floods are unlikely to occur in all the rivers simultaneously. These discharges again, it must be remembered, are only *rates for a short period* and in the upper reaches before the rivers begin to spill The corresponding rate of discharge into the Bhagirathi under the same maximum conditions would be about 195,000 cusecs, but this could never be obtained as the raised level of the river under the circumstances would tend to head back the supply, and so reduce the rate of discharge Under maximum conditions, as at the end of September 1916, the rate of discharge from the western tributaries into the Bhagirathi would be about 120,000 cusecs, being the difference in discharges at Geria and Katwa without allowing for slight reservoir action in the raising of the river level, under ordinary maximum conditions, the discharge would reach about 73,000 cusecs, as in October 1917

Maximum united discharge of all western tributaries of Bhagirathi

Maximum rate of discharge into the Bhagirathi

35 The mean discharge from these western tributaries is now apparently about 27,000 cusecs for the six months from June to November, representing a total quantity of about 15,800 million cubic yards Leonard in 1865 calculated from the best data then available, that the united discharge in times of high flood is over 300,000 cubic feet per second, and during the remainder of the rains for 3½ to 4 months, about 70,000 cusecs These figures are probably intended to represent the discharge before the rivers spill and not the actual discharge into the Bhagirathi. From Leonard's figures, Mr Vernon Harcourt estimated the average yearly discharge of the tributaries of the Bhagirathi at about 40,000 million cubic yards, but varying considerably according to the rainfall. This seems obviously overestimated and the same error vitiates his calculation of a maximum discharge of 650,000 cusecs past Calcutta which, as will be shown later, it would be impossible to obtain This maximum discharge he has obtained by adding the maximum spill from the Ganges of 200,000 cusecs to the maximum discharge of 450,000 cusecs for the Bhagirathi tributaries It will have been seen that this latter maximum discharge may possibly, under very exceptional conditions, be the rate before the tributaries begin to spill, but with a simultaneous high flood level in the Bhagirathi, the supply could not possibly be discharged into the latter river. Flooding would inevitably occur in the valleys and the rate of discharge into the Bhagirathi would probably sink to less than a quarter of the estimated amount

Mean discharge during rains

Total quantity of discharge

Leonard's estimate

Vernon Harcourt's estimate

36. A discharge of 15,800 million cubic yards from the Bhagirathi tributaries would correspond with a general mean run off of about 52 per cent from the 6,700 square miles of basin drained by these rivers, during a year of average rainfall of 53 inches Taking the conditions of spill and the large amount lost by absorption, transpiration and evaporation, the eventual "run off" into the Bhagirathi would probably not exceed this quantity. It will be noted that Mr Vernon Harcourt's figure of 40,000 million cubic yards would exceed the total rainfall over the whole basin in an average year by 31 per cent., the run off percentage in that case being 131 per cent

General mean eventual run off about 52 per cent from the basin

With Vernon Harcourt's estimate, run off would be 131 per cent

37. For the computation of the total discharge of the Bhagirathi, observation stations have been established and measurements taken at intervals of a few days, since 1914, at the following places, Geria, Jangipur, Berhampur, Jumjumkhali, Dattabati and Katwa. The Geria discharge gives the inflow from the Ganges, the Jangipur and Berhampur discharges include the inflow from the Banslai, and the Jumjumkhali station records the total discharge with the supply from the Jumjumkhali nullah The Dattabati discharge takes in the supply from the Dwarka, and the Katwa observation includes the Adjai

Total discharge of Bhagirathi

Observation stations

---

* The run off in this district may average as high as 80 per cent, but as the river spills in high flood, the calculated percentage is naturally reduced

water. The observation at the latter station, therefore, gives the total supply of the Bhagirathi, including the spill from the Ganges and the influx from all the western tributaries. The manner of taking the observations will be dealt with later, but it may be here remarked that the results are in many cases uncertain, owing to the wide differences obtained by the two methods and the discharges given may, therefore, be regarded only as fair approximations *

Dry season flow

Discharge at Berhampur in dry season

Flood season discharge

Maximum flood discharge 1885

Maximum inflow from Ganges 150,000 cusecs

38 It has been seen that from December to June, there is usually practically no inflow from the Ganges, some years being better than others For instance in 1911 the least discharge was 655 cusecs at the entrance in January, averaging about 3,000 cusecs in the remaining months of the dry season, February to May, whereas in other years, the entrance was dry early in December and remained so till the Ganges level rose sufficiently to spill at the end of June. When the entrance is practically or totally closed, the discharge at Berhampur is the small amount, about 300 cusecs, due only to percolation, but when the entrance is open, a fair discharge is obtained at Berhampur, so that an average flow of slightly over 1,000 cusecs was measured during March, April and May 1911. The discharge increases rapidly in July and rises in recent years to a maximum of about 80,000 to 90,000 cusecs in August. With the entrance better placed, or in improved condition, the maximum discharge would probably be considerably greater, particularly in a high flood year of the Ganges. For instance in 1885 when the Laltakuri breach was passing 50,000 cusecs, the gauge at Berhampur fell only 5½ inches the first day and at a reduced rate thereafter, till it had fallen 1'-1½" in five days On the 6th day, the level commenced to rise again though the same quantity was estimated to be still passing through the breach The supply down the main stream sufficient to keep the gauge height near the record stage level at that time must have been at least 100,000 cusecs, with a sectional area at Berhampur of 30,000 square feet, giving a mean velocity of 3 33 feet per second which is not excessive The inflow from the Ganges must, therefore, have been approximately 150,000 cusecs.

Discharge in 1890

39. In 1890 when a small breach occurred, the sectional area at high flood level was about 31,000 square feet This was a record year of high levels even at Calcutta, so that a velocity of 4 feet a second may be taken as a moderate estimate and this would give a discharge of 124,000 cusecs at Berhampur exclusive of the quantity passing through the breach The influx from the Ganges may, therefore, be estimated to have been nearly 150,000 cusecs, as in 1885 This, therefore, may be regarded as the maximum discharge in a year of abnormal floods, but it is doubtful whether the Bhagirathi could carry it without spilling, particularly if the tributaries were bringing down a fair discharge

Total maximum discharge at Katwa 200,000 cusecs

40. The discharge from these western tributaries under ordinary maximum conditions has already been estimated at about 73,000 cusecs, so that the discharge of the Bhagirathi at Katwa may reach under abnormal conditions a maximum of 223,000 cusecs Extensive flooding would almost inevitably occur under these conditions of discharge, as, on the 25th September 1916, with a measured discharge of 170,000 cusecs, the gauge level at Katwa was 53' 82 above datum, only 8½ inches lower than the record gauge level of 1890, and the town of Katwa was flooded in parts The spill would regulate the rate and the maximum discharge obtainable in the Bhagirathi at Katwa may, therefore, be taken as about 200,000 cusecs

Mean discharge at Geria and Katwa

Total annual discharge 36,000 million cubic yards

41 The mean discharge from the Ganges during the freshet months from 1st June to 30th November in recent years appears to have been about 33,000 cubic feet a second, representing a total quantity of 19,324 million cubic yards The mean discharge at Katwa would, therefore, be about 60,000 cusecs for the six months from 1st June to 30th November and the total supply from the Bhagirathi for this period would, therefore, on the average be about 35,000 million cubic yards. For the remaining months, the total discharge would range from 500 to 1,000 million cubic yards, or, say, a total of 36,000 million cubic yards for the whole year With higher flood years and with the entrance in better condition, or with greater precipitation over the western basin, the total supply to the Hooghly would probably be over 40,000 million cubic yards.

Slope of Bhagirathi

Fall from Geria to Katwa

Fall from Jangipur to Berhampur

Fall from Berhampur to Katwa

Fall increases from Katwa to Nadia

42 The slope of the Bhagirathi is variable and it is difficult even to determine the general slope with any accuracy, as, in the absence of recent surveys, distances for the upper part are only approximately known From Geria to Katwa, the fall is ordinarily about 29 feet, and the distance being approximately 100 miles, the general slope would be 3·48 inches to the mile From Jangipur to Berhampur, a distance of approximately 45 miles, the fall in the early months of 1917 was 13 feet, giving a mean slope of 3 47 inches to the mile. It increased in the middle of June to 15 feet representing a slope of 4 inches to the mile, but at the height of the flood on the 14th August the fall had been reduced to 11'-8", giving a slope of 3 1 inches to the mile From Berhampur to Katwa, a distance of 48 miles, the fall in the dry season of 1917 was about 13'-6" representing a slope of 3 37 inches to the mile During the flood season, the fall varied considerably, as the variable discharge from the Babla and Ajai rivers affected the Katwa levels. The maximum fall was 15 feet 6 inches and the minimum 6 feet, giving slopes of 3·88 inches and 1 5 inches, respectively. The mean slope may, however, be taken as 3·4 inches to the mile. From Katwa to Nadia, the fall increases, this being probably the effect of the various loop channels, such as the old Agradwip loop According to the present values of the Katwa and Swarupganj gauges, the fall is about 16 feet in the dry season in the distance of 41 miles, giving a slope of 4 7 inches to the mile. During the flood season, it varies between 3·37 inches and 5 7 inches These slopes appear excessive, even with the various loop channels, and there seems to be some uncertainty about the value of the

* Plate No 4 and statements G H & I

Swarupganj gauge readings which may be too low Making a general allowance for this, the slope would be about 4·1 inches to the mile in the dry season, varying between 2·8 and 5 1 inches during the flood months. The great variability appears to be the effect of the cutting through of the great Agradwip loop, as the Patuli Khal apparently is not yet capable of carrying the discharge without difficulty and there seems to be some obstruction until the level rises high enough for the Agradwip loop also to operate freely

Obstruction at Patuli Khal

Slope at the entrance

43. The slope at the entrance is particularly variable, owing to the restrictions to the flow of water under present conditions Between Geria and Jangipur, it appears to vary usually between 4 and 7 inches to the mile, but at times the slope rises as high as 12 inches Statement K taken from the Executive Engineer's dredging report for 1912-13 shows the wide variations, the fall having been 3½ inches in the first mile from Bishwanathpur, 15¾ inches in the second mile and 14¾ inches in the third mile, with a general fall of 11 inches to the mile in the whole length in that season.

General mean slope of river Bhagirathi

44. The total general fall of the river from Geria to Nadia may be estimated at about 43 feet, giving a general mean slope of 3 66 inches to the mile

Silt carried in suspension

Experiment by Executive Engineer, Murshidabad Branch, E B Railway

Mr C G Livesay's determination of 1 8 cubic inches to a cubic foot

45 The proportion of silt carried in suspension in the water of the Bhagirathi has not been determined by any recent experiments In 1904 on the 19th August, practically at high flood level, the Executive Engineer, Murshidabad Branch, Eastern Bengal Railway, took a set of observations at different depths in mid-stream and also near either bank of the river at Berhampur The percentage varied considerably, but the mean result gave about 353 grains to the cubic foot corresponding to about 1·[illegible] cubic inches to a cubic foot In 1893, Mr C. G. Livesay, Executive Engineer, Nadia Rivers Division, carried out some extensive experiments at Berhampur. These were analysed by Mr Apjohn in his lecture on the subject at the Sibpur Engineering College in 1895 The tests were taken at different depths on three days in August and three days in November, corresponding to the flood and dry seasons The mean of all the observations gives a proportion of 518 grains or 1 81 cubic inches in a cubic foot According to Mr Livesay's experiments, the silt carried was in greater proportion and increased more rapidly on a rising than on a falling river and this accords with the general rule Mr Apjohn further determined a law of arithmetical increase, showing that the proportion of silt increased generally by one-tenth for each foot below the surface It is probable that the proportion of silt carried by the Bhagirathi's tributaries, such as the Dwarka and Ajai, is somewhat greater than that carried in the Ganges spill water, but from other experiments at Calcutta, which will be referred to later on, though no absolutely reliable data have so far been obtained, the mean proportion may be taken as 480 grains or 1 68 cubic inches, to a cubic foot without the probability of considerable error The total average quantity of silt carried down in a year by the Bhagirathi would, therefore, be 34 million cubic yards representing a solid block 1 mile square and 33 feet thick

Increased proportion of silt on rising river

Increase of proportion with depth below surface

Total quantity of silt carried down annually by Bhagirathi

Bhagirathi's silt charge less than that of Ganges

46 It has been seen from Mr Livesay's experiments that the density of the silt charge increased with the depth. As the bed of the Bhagirathi is much higher than the bed of the Ganges, it follows that the spill water entering the river would be drawn from the upper layers, carrying a smaller proportion than the general Ganges silt charge and this is borne out by the figures already given The Ganges charge varies from 575 to 924 grains to the cubic foot according to different estimates, taking the mean as approximately 776 grains, this is about 50 per cent greater than the silt charge given for the Bhagirathi In a year when the entrance is well open therefore, the density of the silt entering the river will be greater than in a year when the bed is high, and the proportion of heavier sand to the mud carried in deposit will be greater The bed of the Bhagirathi is composed of sand, the very finely divided particles of mud being borne along in suspension and settling only in sheltered places where the water is still When left undisturbed for any considerable period of years, the deposit hardens into clay, the fine mud deposit forming in the course of centuries the tenacious blue clay so common along the courses of these rivers. In any cutting bank on the Bhagirathi, the deposit may be seen laid in well defined strata of sand and mud, topped by a layer of mud from 4 inches to 4 or 5 feet in thickness, forming a rich soil for vegetation The sand in these banks when attacked by the current is easily washed out and consequently the whole bank crumbles into the river As the high caving banks are in the bights above the shoal crossings, the masses of disintegrated material are to a great extent dropped where the current slackens on the crossings and help to keep the bars high. This detritus also maintains the silt charge, more or less balancing the deposit which is continually taking place in sheltered portions

Proportion of heavier sand greater when entrance is well open

Bed of Bhagirathi composed of pure sand

Deposit in strata of sand and mud

Disintegration of banks

Sectional area

47. The sectional area of the Bhagirathi at Geria below high flood level of 1890 was in 1914, 27,500 square feet. With the recent raising of the bed level, the sectional area has decreased progressively to 25,000 square feet in 1915, 24,720 in 1916, and in 1917 it was only 22,700 square feet. At Jangipur, the sectional area below the 1890 flood level was about 27,800 square feet in 1914, 1915 and 1916, and in 1917, it decreased to 22,500 square feet. At Berhampur, the sectional area below the 1890 flood level was about 33,300 square feet in the years 1914, 1916 and 1917. In 1915, it was 35,230 square feet, and at Katwa the area below the 1890 flood level was 38,300 square feet in 1914, increasing to 47,600 square feet in 1915. In 1916 and 1917 it was about 43,500 square feet

Shoals in Bhagirathi

Bhagirathi Shoals in 1914-15

48. In order to give an idea of the present conditions of shoals in the Bhagirathi, it is necessary to trace in a general way the history of the past few years In the year 1914-15 there were 40 important shoals in the Bhagirathi, 23 in the upper section and

17 in the lower section and of these 26 shoals with a total length of 90,700 feet were trained. The least depth at the entrance fell to 3 feet on the 9th October when dredging was commenced. By the 20th November, the depth was 2 feet 3 inches on the Lalkhandiar shoal between Jangipur and Berhampur the least depth had fallen to 2 feet and this was also the least depth between Berhampur and Katwa. The entrance was practically dry in December and in the latter half of the month, the flow was outwards from Geria into the Faracca channel, so that later to prevent this, a bund had to be thrown across the mouth. A channel was scraped through the sand by hand labour from the 9th December and this maintained a connection between the entrance and Jangipur, sufficient for light dinghy traffic till the end of March By the 4th December, the least depth between Berhampur and Katwa had fallen to only 1 foot and by the 11th December, the least depth was 2 feet between Katwa and Nadia, falling still further to 1 foot 9 inches on the 18th December. Later at the end of December the least depth was only 6 inches between Berhampur and Katwa and fell to 3 inches at the end of March In the section between Katwa and Nadia the depth improved at first, but for a week in the middle of April fell to 1 foot 6 inches The river commenced to open again about the 11th June, when 1 foot depth was obtainable between Jangipur and Katwa and 3 feet between Katwa and Nadia By the beginning of July, there was 3 feet depth over the Momintola shoal at the entrance, 5 feet between Jangipur and Katwa and 10 feet between Katwa and Nadia

Shoals in 1915 16

49 In 1915-16, there were 39 shoals in the river, 28 in the upper and 11 in the lower section of these 23 shoals with an aggregate length of 62,800 feet were trained. The least depth at the entrance was 2 feet on the Lalkhandiar shoal on the 29th October 1915 and the entrance was absolutely dry by the middle of December by January the flow from Geria was outwards through the sand into the Faracca channel The least depth between Jangipur and Katwa was 2 feet 6 inches on the 12th November, when 5 feet was available between Katwa and Nadia. By the 26th November the depth between Jangipur and Katwa fell to 1′ 6″ and between Katwa and Nadia to 3 feet, which dropped further to 2 feet at the beginning of December The least depth between Jangipur and Katwa fell gradually to 6 inches on the 11th February and remained steady for the remainder of the dry season Between Katwa and Nadia the least depth fell to 1 foot at the end of January and to 9 inches in the middle of March

The usual rise took place suddenly at the end of June, on the 30th of which month 10 feet was the least depth through the river

Shoals in 1916 1917

50 In 1916-17 there were 58 shoals in the river, 43 in the upper and 15 in the lower section of these 25 with an aggregate length of 59,400 feet were trained The least depth at the entrance fell to 2′ 6″ on the Lalkhandiar shoal on the 27th October The channel was practically dry with only 3 inches on the 12th January and the outward flow into the Ganges commenced in February 1917 The least depth fell to 3 feet between Jangipur and Berhampur on the 10th November and to 2 feet between Jangipur and Katwa on the 24th November, when 5 feet was available between Katwa and Nadia In the beginning of January only 1 foot was the least depth between Jangipur and Katwa, while between Katwa and Nadia the depth had fallen to 2′ 3″, which dropped to 1′ 9″ at the end of that month, but improved again to 2 feet subsequently For the remainder of the dry season 9 inches was the least depth between Jangipur and Katwa and 1′ 9″ to 2′ 3″ between Katwa and Nadia

Shoals in 1917 1918

51 In 1917-18 there were 62 shoals in the river, 47 in upper and 15 in the lower section, of which 28 with a total length of 79,000 feet were trained The least depth at the entrance fell to 2′ 6″ on the 9th November and the entrance was quite dry by the 23rd November 1917. The least depth between Jangipur and Katwa which was 3 feet on the 9th November, fell to 1 foot on the 16th November, but improved to 1′ 6″ by the end of the month when the depth between Katwa and Nadia was 4′ 6″. At the beginning of January, 1918, 1′ 3″ was available between Katwa and Nadia These depths fell to 1 foot and 2 feet, respectively, by the end of February and remained at about these figures till the river commenced to rise at the end of May below Katwa and the middle of June below Jangipur.

52 The following statement shows the least depth in each section of the river during the dry season and the maximum depth during the flood months in the past six years It will be noticed that with an increase of stage of about 24 feet, the maximum increase of depth is from 4 to 9 feet less

	Least Depth.												Maximum Depth.							
Sections ..	. 1913		1914		1915		1916.		1917		1918		1913.		1914.		1915.		1916	
	Ft	in.	Ft.	in.	Ft	in.	Ft	in	Ft	in.	Ft	in.	Ft.	in	Ft	in.	Ft	in	Ft.	in
From entrance to Jangipur.	1	0	0	4	Dry		Dry		Dry		Dry		18	0	21	0	15	0	16	0
Jangipur to Berhampur	1	0	1	0	0	6	1	0	0	9	1	0	19	0	19	6	18	0	20	0
Berhampur to Katwa ..	1	0	1	0	0	3	0	6	0	9	1	3	20	0	21	0	18	0	20	0
Katwa to Nadia ...	1	0	1	6	1	6	0	9	1	9	1	9	20	0	22	0	19	0	31	0

53 Before proceeding to deal with the general questions of deterioration and the methods of improvement which have been employed, it is necessary to consider the present conditions of the Bhairab-Jalangi and Mathabhanga rivers, so far as the information available, which is unfortunately scanty, permits

Bhairab-Jalangi river

General condition of level

54. The Bhairab, as stated before, opened in 1874 and in the eighties developed into the main entrance channel of the Jalangi It now takes off from the Ganges about 10 miles west of Akriganj. The level at the latter place is usually dead at a mean height since 1890 of 43′ 1″ above Kidderpur Old Dock Sill till May. It begins to rise usually at the beginning of June and generally by the end of that month reaches the 50-feet stage, rising to the 60-feet stage in the middle of July The maximum flood level at a mean height of 69′ 4″ is attained usually by the end of August and by the first week of October the level has fallen again to 60 feet, returning to the 50-feet stage by the first week in November.

Slope of Bhairab-Jalangi

55. The fall of the river from Akriganj to Swarupganj near Nadia varied, according to present values of the gauges, between 27 and 39 feet, in 1917. At low flood the fall is about 34 feet and at high flood 33 feet, the mean fall being approximately 33′ 6″ which might require a minus correction of about 2 feet As the length of the river between the stations is approximately 140 miles, the general mean slope is only about 2 7″ per mile The discharge during the dry season is, as in the case of the Bhagirathi, due to percolation amounting in the lower reaches to about 400 cusecs In the flood months the discharge is practically all spill from the Ganges with some surface drainage The chief observation station is at Tilakpara above Panditpur, but discharges are also measured at Akriganj. The maximum discharges at the latter station in 1914, 1915 and 1916 were 85,000, 78,000 and 79,000 cusecs, respectively. The Bhairab bifurcates at Banti below Akriganj where the old Bhairab diverges, taking off a certain amount of flood spill, but this stream enters the main river again at Muktiarpur, where the latter receives also the old Jalangi, carrying the flood spill from the Sialmari river Information regarding the present quantity of this increment is not available, but it cannot be a considerable amount and when the Bhairab level is high, the water in the Jalangi channel is backed up

Discharge conditions

Maximum discharge

56 The maximum discharge recorded since 1915 at the Panditpur Station was 84,900 cusecs by Kutter's formula and 69,900 by the float method and in a record year such as 1890, it would probably reach 100,000 cusecs, but spilling would occur, and if the Bhagirathi level at Nadia was high the rivers would mutually restrict each other's discharge

Mean discharge

57 The mean discharge during the flood season from 1st June to 30th November appears to have averaged recently about 31,000 cusecs, representing a total quantity of 18,000 million cubic yards The total discharge for the whole year would probably be about 19,500 million cubic yards

Silt charge

58 The silt proportion being taken as the same as in the Bhagirathi, the total quantity brought down in a year would be approximately 17½ million cubic yards

Though caving action is very marked in places, the banks of the Jalangi in the lower section appear to be of fairly stiff material and do not usually present the regular strata of mud and loose sand seen in the Bhagirathi

Shoals in Bhairab-Jalangi

59 In the year 1916-17, 13 important shoals in the river with a length of 21,485 feet were trained. The following statement shows the least and maximum depths in the Bhairab-Jalangi since 1913 —

	LEAST DEPTH						MAXIMUM DEPTH				
	ft in	ft. in	ft in	ft in	ft in	ft in	ft in	ft in	ft in	ft. in	ft. in
Sections	1913	1914	1915	1916	1917	1918	1913	1914	1915	1916	1917
Entrance to Akriganj	0 6	0 6	0 9	Dry	Dry	Dry	22 0	20 0	17 0	22 0	19 0
Akriganj to Muktiarpur	1 3	1 6	1 3	1 3	1 0	0 9	24 0	23 0	19 0	21 0	21 0
Muktiarpur to Patkabari	2 3	2 0	1 6	2 0	2 0	1 9	23 6	25 0	20 6	22 6	22 0
Patkabaria to Nadia.	2 0	2 0	1 6	1 9	1 0	1 9	21 0	16 6	20 0	22 0	24 0

Matabhanga-Churni

60 The Matabhanga takes off from the Ganges just above the village of Jalangi at the old Jalangi entrance. Gauges are established at Dewanganj, about 7 miles from the entrance and at Hanskhali in the Churni about 24 miles from the outlet into the Hooghly near Chakdaha, the river channel between the stations being approximately 95 miles in length The river level at Dewanganj usually begins to rise in the middle of June from the mean dead level of 42′ 9″ and attains its mean maximum height of 64′ 3″ since 1906, generally about the end of August There is usually a subsidiary rise and the level falls from the end of September The entrance is usually dry in the cold season

General conditions of level

Slope

61. The fall from Dewanganj to Hanskhali in the dry season is 28 to 29 feet and varies during the flood season between 33 and 25 feet, the greater fall being when the

inundation first affects the Dewanganj levels and the less when the crest of the flood wave has passed into the lower section.

The mean fall is about 28′ 6″ which in a length of 95 miles gives an average slope of about 3·6 inches per mile.

Discharge conditions

62. The maximum discharge of the Matabhanga at Dewanganj as recorded in 1914, 1915 and 1916 was between 22,000 and 23,000 cusecs, but this has been probably underestimated and the maximum discharge would probably reach from 36,000 to 40,000 cusecs At Hanskhali the maximum discharge in the past three years ranged between 10,000 and 12,000 cusecs, the surplus being taken away by the Kumar and Ichhamati rivers.

63. In 1917 with a sectional area of about 5,000 square feet at Hanskhali, the discharge was approximately 12,000 cusecs so that in a record year such as 1890 with sectional area of about 6,800 square feet, the discharge might reach to 15,000 to 16,000 cusecs, but, if the Bhagirathi and Jalangi discharges were simultaneously abnormal, the Matabhanga discharge would be restricted owing to the raising of the Hooghly level The mean discharge into the Hooghly during the freshet months from 1st June to 30th November according to figures in recent years, appears to average about 5,500 cusecs and the average total discharge during a year is about 3,400 million cubic yards

Silt charge

64. Taking the silt percentage as before, 1·68 cubic inches to a cubic foot, the average total quantity of silt brought down in a year would be 3 million cubic yards

65 The percolation supply during the driest months appears to average between 400 and 500 cusecs and as the river widths are much less than in the Bhagirathi and Jalangi, this suffices to keep a fair depth in the lower section, as will be seen in the accompanying statement, showing the least and maximum depths in the river since 1913.

	Least depth												Maximum depth.							
Section	1913		1914		1915		1916		1917.		1918		1913		1914		1915		1916	
	ft	in	ft.	in	ft	in.	ft.	in	ft	in	ft.	in.	ft.	in.	ft	in	ft	in	ft	in
Entrance to Dewanganj	0	6	0	6	Dry		0	3	Dry		Dry		17	6	21	0	13	6	13	0
Dewanganj to Shikarpur	1	3	1	0	1	3	1	0	1	0	1	0	17	0	20	0	15	0	18	0
Shikarpur to Boalia...	2	3	6	6	5	9	6	6	2	6	2	9	21	3	20	9	20	0	16	3
Boalia to Chuadanga	2	6	5	9	5	0	5	0	2	6	..		21	6	20	6	18	9	16	9
Chuadanga to Hanskhali	4	0	4	0	3	6	3	3	3	0	4	3	21	0	21	0	20	0	16	3

Variation of depth at entrance

66 The manner in which the depth at the entrance varies is shown in the records of recent years In the dry season of 1915 the entrance was dry, but the depth increased with the rise of the river till the middle of August, when 13 feet 6 inches was available with a rise of stage of 18 feet A week later with 1 foot more on the gauge, the depth at the entrance had fallen to 8 feet and still further to only 6 feet 9 inches by the end of August. On the 10th September at high stage level, the depth was 7 feet 6 inches with a rise from low stage level of 20 feet and on the 17th September with a fall of stage of 2 feet, the depth fell to 3 feet, so that the bed level had risen about 14 feet since the beginning of the year It then scoured down till at the end of the year, the depth had fallen only 2 feet with a fall in stage level of nearly 20 feet In the previous year 1914, at high stage level on the 14th August, the depth was 22 feet as compared with 13 feet 6 inches in 1915 From 17 feet on the 11th September the depth fell rapidly to 3 feet on the 9th October, when the stage level was 3 feet 6 inches lower than on the 17th September 1915 In 1916 the maximum depth was only 13 feet on the 8th September with a rise of 23 feet from low stage level and yet did not fall to 3 feet till the 15th November, when the stage level was 8 feet 6 inches lower than when the depth fell to 3 feet in 1914 and 12 feet lower than when it fell to the same depth in 1915.

Summary of Discharges and Silt carried by Nadia Rivers.

		Maximum discharges		Ordinary High flood discharges	
Bhagirathi	From Ganges	150,000	cusecs	80,000	cusecs
	Western Tributaries .	120,000	„	73,000	„
	At Katwa .. .	200,000	„	150,000	„
Bhairab-Jalangi at Panditpur ..		100,000	„	70,000	„
Matabhanga Churni at Hanskhali .		16,000	„	10,000	„
Maximum combined discharge into Hooghly		300,000	„	230,000	

Summary of Discharges and Silt carried by Nadia Rivers—*concld*

	Ordinary total discharges for whole year		Ordinary total discharges during freshets, 1st June to 30th November	
Bhagirathi ...	36,000	million cubic yards	35,000	million cubic yards
Bhairab-Jalangi ...	19,500	„ „ „	18,000	„ „ „
Matabhanga Churni	3,400	„ „ „	3,220	„ „ „
Total entering Hooghly	58,900	„ „ „	56,220	„ „ „

Volumes of Dry Silt carried in suspension.

(Silt charge taken as $\frac{1}{1028}$ by volume)

1st June to 30th November

Bhagirathi	34	million cubic yards
Bhairab-Jalangi	17.5	„ „ „
Matabhanga Churni . . .	3	„ „ „
Ordinary total volume of silt carried into Hooghly each season	54.5	„ „ „

This represents a cube of matter one mile square and 52¾ feet thick

---

CHAPTER IV.

Alleged deterioration of the Nadia Rivers and suggested remedies.

Determination of deterioration difficult owing to lack of data

The lamentable paucity of material data and records makes it difficult to find a satisfactory solution to the vexed question whether there has been a progressive deterioration in the Nadia rivers

Alternation of good and bad periods mask general tendency

2 From the history which has already been given, it will have been seen that the rivers pass through successive phases of deterioration and improvement, the conditions in each case being largely governed by the situation and state of the intakes from the Ganges which vary continually These alternations of good and bad periods help to mask the general tendency and in the absence of continuous records are apt to mislead the casual investigator

Raising of bed levels and reduction of sectional area

Longitudinal sections

3 The general and progressive deterioration of the rivers involves two factors influencing their discharge, and these are the general raising of their bed levels in relation to the parent stream, the Ganges, and the reduction of their capacities as expressed in terms of sectional area The general raising of bed level would be shown by a comparison of longitudinal sections along the axis of the river taken at intervals, but unfortunately one longitudinal section of the Bhagirathi only is available, and that taken as recently as 1913 by Mr Cowley In the absence of a series of previous comparative sections, this is useless for the present purpose

Comparison of sectional areas

4. A reduction in capacity attending elevation of bed level may also be shown by the diminution of cross sectional areas along the river channel. This, however, in a river with an unstable regimen and varying sectional areas is a difficult problem where the comparative sections available are few and isolated, owing to the uncertainty as to exact position where the later sections should be taken for comparison With a channel and cross sectional area both varying, it is obvious that cross sections taken at exactly the same place, which at one time may be in a bight and at another in a straight reach, may give very misleading results, especially if taken at different seasons

5. Comparative sections are available at Jangipur and Berhampur taken in the years 1860, 1877, 1895 and also in recent years. At these stations the sections gave the following areas below High flood level of 1890 —

	Year	Sectional area Sq ft
Jangipur	1860	26,050
	1877	30,300
	1895	26,500
	1916	27,800
	1917	22,500
Berhampur ...	1860	39,000
	1877	34,640
	1895	33,230
	1915	35,230
	1916	33,300
	1917	33,180

Indications of slight reduction of sectional area at Berhampur

Reduction at Geria in recent years

6. The results are, as might be expected from single sections, indefinite at both places, though at Berhampur there are indications of a contraction in sectional area

7. It has already been pointed out that at Geria with the increasingly unfavourable condition of the offtake, the sectional area has diminished progressively in recent years from 27,500 square feet in 1914 to 22,690 square feet in 1917.

Effect of deterioration on river levels

8 The progressive general elevation of bed level may also be determined by its effects on the river levels at high and low stages and particularly on the latter. Gauges have been in existence at various places for a considerable number of years and though, till quite recently, there was some uncertainty regarding their relative values, the records, if continuous, could without difficulty have been co-ordinated. Unfortunately, the majority of early records appear to have been mislaid or destroyed and the only complete series now available are the Berhampur gauge levels which extend back no further than 1861

Gauge levels at Berhampur available since 1861

Those have been reduced to the present datum value of Kidderpore Old Dock Sill and are shown graphically on Plate No 1 together with the levels at Jangipur and Katwa since 1890, similarly reduced The Berhampur high and low flood levels have been meaned in periods of ten years and an examination of Statement C will show a gradual progressive rise of the average high flood level from 64 feet above datum in the decade 1861-1870 to 66 feet 8½ inches in the period 1901-1910 Making adequate allowance for reduction in level on account of breaches in the embankment, the rise in average flood level at Berhampur was approximately 2 feet 6 inches in the forty years separating the decades under consideraion Subsequently the mean flood level fell and in the past seven years was 65 feet 3½ inches, that is 1 foot 5 inches lower than the immediately previous average and yet 1 foot 4 inches higher than the average in 1861-1870 This high flood level is of course largely dependent on the Ganges flood level of which there are unfortunately no reliable records extending so far back, but the consistent and progressive rise in each successive decade till the last, is significant in the absence of any indications of a corresponding general rise of the Ganges level The fall in the last seven years, in spite of an apparent rise of the average Ganges level at Rampur Boalia in the same period, can only be attributed to the very unfavourable position of the intake, and an examination of the Geria and Jangipur records (Statements A & B) shows a corresponding fall of 1 foot 2 inches since 1890

Examination of Berhampur high flood levels

Rise of high flood level

Effect of embankments on flood levels

9. In some quarters a general rise in high flood levels is regarded as a necessary accompaniment of embanking a river and is taken to indicate a raising of bed level It is true that at first the construction of embankments by confining the spill water to the river channel raises the flood level, but in alluvial streams not too heavily charged with silt, the channel generally re-acts to the greater discharge by increasing its sectional area and the tendency later is to lower the bed level rather than to raise it and the flood levels respond by falling Mr. B M Samuelson arrived at this conclusion in his note on the Irrawaddy and this is supported by the effect of levees on the Mississippi, which, according to the report of the Chief of Engineers, U S. A, 1912, indicate "a decided depression of the bed for a large portion of its length and point to a general enlargement of the cross sectional area of the stream below the high water banks"

Conclusions from Irrawaddy and Mississippi

Effect of embankments on rivers of Tista and Damodar class

10. The Bhagirathi is a typical alluvial spill stream flowing through a bed of its own formation and carrying a charge of very fine sand and silt It differs widely from torrential streams such as the Tista and Damodar which carry a heavy grade of sand, which is rapidly transported to a spilling ground where the slope is much reduced In these cases a rise of bed level may possibly be expected, should the deposit be restricted to the river channel by embankments, as has been observed in the cases of the lower channels of the Reno and Adige rivers in Italy.

Rise in flood level due to raising of bed level of Bhagirathi

11 The Bhagirathi embankments have been in existence for a considerable number of years and in the circumstances, the rise in flood level cannot be ascribed solely to them However, as there seems no evidence that the Ganges flood levels have been raised correspondingly, the elevation must be attributed in part at least to a raising of bed level in the half century through natural deterioration and the fall in recent years is probably due to the restriction in discharge beyond a critical point

Effect on low stage level

12 A more reliable test, however, is afforded by a comparison of the low stage levels. As stated before, the low stage level at Berhampur is dependant on two factors, percolation and supply from the Ganges The former may be regarded as practically invariable and as the occasions on which the entrance has been sufficiently open to affect the levels considerably have been rare, the general variations from this source will be largely eliminated by taking ten year periods.

Examination of Berhampur low stage levels

13. Now examining the Berhampur gauge curve on Plate No. 1 and also Statement C, the gradual progressive rise of the low stage level is very clearly revealed. Where 50 years ago the low stage was generally 36 to 37 feet above datum, the level now only falls to 40 and 41 feet. The progressive rise is even more clearly marked if the influence of the Ganges supply when the entrance was open, is taken into consideration, for instance in 1871-1872 the opening of the Chaurasia intake raised the level from an average of about 37 feet suddenly to 40 feet and again in 1885-1886, the Kaligunj entrance had a somewhat similar effect

14. In recent years, except 1911—where the influence is marked—we know the entrance has been usually dry and in fact there has been a flow outward into the Ganges and yet the low stage level at Berhampur is consistently higher. As this is, therefore, dependant only on the fairly invariable and very small percolation discharge, the only conclusion there can be is that the bed level must have risen since the middle of last century

Rise of low stage river level indicates rise of bed level at Berhampur

15. The extent of this rise was 3 feet 8 inches in the forty years separating the decades 1861-1870 and 1901-1910, at the rate of just over an inch a year In the last eight years, the bed has not risen appreciably, but this may be only a temporary phase, such as in the successive decades 1871-80 and 1881-90.

16 Turning to Statements A and B, we find there has been a corresponding rise in the mean low stage levels at Geria and Jangipur amounting to 32 and 30 inches, respectively since 1890, and 14 inches at Katwa in the same period.

Relation of rise to stage of Ganges low stage level

17. The general raising of the low stage level indicates a progressive elevation of the bed of the Bhagirathi since 1861 The significance of this cannot be appreciated except in relation to the Ganges low stage level. If the latter has been raised *pari passu*, the development is natural and does not imply general deterioration, otherwise the position is very much more serious, but even so, it would be necessary to show that this tendency is not a long period phase and has always been in the same direction It is here at this critical point that the lack of earlier records becomes keenly felt, preventing any certain determination of this crucial point

Fall of low and high flood levels at Akriganj in the Bhairab

It will be noticed that the only river which shows a fall in low and high flood levels is the Bhairab at Akriganj The low flood level fell generally from 47 feet 5 inches and 48 feet 3 inches in 1890 and 1891 to 39 feet 9 inches and 38 feet 9 inches in 1900 and 1902, and then gradually rose again The mean high flood level fell from 70 feet 11 inches in 1890-1899 to 68 feet 5 inches in the decade 1900-1909, but increased again to 69 feet 6 inches in the past eight years This is of course explained by the fact that the Bhairab mouth was open for the greater part of the middle decade, when it will be seen, the mean range of stage was a foot and-a-half greater than in the previous and following periods No general deductions can, however, be drawn from these levels as the situation of Akriganj at the entrance of the river makes the levels liable to great fluctuations due to local causes, as at Geria in the Bhagirathi

The gauge records at Swarupganj which would have afforded some indication are unfortunately unutilizable, as the lowest water readings have not been recorded in the dry season when the levels are affected by the tides

Probable rise of Ganges low stage level

18 As regards the Ganges low stage level, the Rampur Boalia records which reach back to 1885, certainly indicate a slight elevation since 1890, but there are reasons to doubt the reliability of these records and no conclusions one way or another can justifiably be drawn from them It is natural to suppose under the conditions since the end of the eighteenth century, when the Brahmaputra main stream poured into the Ganges channel at Goalundo, that there has been a natural raising of the Ganges bed above the point of junction, but a rate of elevation of the bed of even three-fourths of an inch a year, would in a hundred years have amounted to over 6 feet This would naturally affect the high flood levels, unless compensated for by increased slope owing to the straightening of the channel which has undoubtedly occurred and which may not have reacted on the bed owing to the varying conditions of discharge of the two rivers

Reduction in the rise of Ganges since 1765

19 The conditions of level in the Ganges at the Nadia Rivers appear undoubtedly to have changed since the junction of the Brahmaputra Rennell in his Account gives a 'scale of rise' for Jalangi and Dacca, in which the range at Jalangi is taken as 32 feet He explains that the observations were taken in a year when the rise was more than usual and suggests that the rise normally would be about 31 feet The greatest range in the past 33 years at Rampur Boalia was 29 feet 11 inches in 1885 and the rise since, is generally lower, showing that the rise in stage is now not so great as in Rennell's time before the Brahmaputra entered the Ganges at Goalundo The fall in stage level appears to have occurred early, as in a statement of depths in the Nadia Rivers, by Major Lang in 1853, the average "total rise of river at entrance" from 1840 to 1853 was only 23 feet 6 inches and the greatest rise was 28 feet 7 inches in 1847 It is uncertain whether this total rise refers to the Ganges, but even if it was measured on a gauge inside the entrance of the Bhagirathi, the range in the Ganges could not probably be more than a foot greater, as the Bhagirathi entrance was open with a depth of 2 feet or more for ten years in the fifteen under consideration

Rise of Ganges according to Lang in 1840-53

Range at Geria 2 feet greater now than in 1840-53

20 At Geria the average range of stage in the 28 years since 1890 has been 25 feet 8½ inches, or over 2 feet greater than the range from 1840 to 1853 It seems, therefore, that the Ganges flood levels must have fallen considerably after the combined rivers developed a satisfactory outlet into the Meghna, and the tendency subsequently has been for them to be raised again

21. The probable rise in bed level of the Ganges at the Nadia rivers would minimize the present significance as regards deterioration, of the rise of bed at Berhampur, as without a corresponding extension of the Hooghly outlet into the Bay, the effect would be simply to steepen the slope of the Bhagirathi This has an element of danger for the future as the country through which the rivers run has not been correspondingly raised

22. The phase may, however, be only temporary and with a satisfactory inlet, or during a period of higher floods, the bed level may again be lowered, though in the process a great strain will be thrown on the embankments

If bed level of Bhagirathi has risen without corresponding rise of Ganges bed level the effect on navigation would now be obvious

23. If the Ganges bed level has not risen, the rise in low stage level at Berhampur undoubtedly points to deterioration since 1861. The same rate, however, cannot have been maintained from a much earlier period, as in that case the bed level in relation to the Ganges would have been raised to such a height that the slope of bed from the entrance in the dry season, would have been much flatter than it is and the obstructions, or bars in the channel would have become more numerous and so much greater than in past times as to be obvious. Therefore, the only

test which remains, in the absence of comparative sections and continuous gauge records, is the evidence as regards the difficulties of navigation. Before considering this, however, it is necessary to deal with a point which has considerable bearing on the matter. It has been pointed out that the low stage level of the Ganges usually falls below the bed level at the entrance of the Bhagirathi, but this level varies in height in different years. When the low stage level is above the average, the difficulty of providing a flow through is naturally not so great as at other times. Now according to the figures supplied to Major Hirst, an average of 7,500 cusecs were taken in during the dry season months at the headworks of the certain systems of the Gangetic canals between 1894 and 1914 and Mr Nethersole, Inspector-General of Irrigation, informed him that a maximum amount not exceeding 10,000 cusecs was probably abstracted from the Ganges by all the Ganges canals. This would be an unnoticeable quantity when the Ganges was carrying its full flood discharge of 1,500,000 cusecs, but becomes a large fraction when during the dry season the discharge has sunk, according to Sir Francis Spring to between 40,000 and 50,000 cusecs near Sara, *vide* plate 6.

Abstraction of water by Ganges canals

Effect of abstraction on low season discharge and level

24. The quantity taken away is then from 15 to 20 per cent of the whole discharge and this loss must have affected the low water levels since the canals were opened, probably causing a general reduction in level of over a foot, thereby increasing to that extent the difficulty of maintaining the entrances of the feeders open to the Ganges.

Bhagirathi head dry 1666 and in 1765

Closed by sandbank 15 feet high about 1780

25. The earliest reference to obstruction as already stated is that of Tavernier, that the Bhagirathi head was dry in 1666. A hundred years later in Rennell's time it was again unnavigable in the dry season by boats and the head was, therefore, either dry or had less than 2 feet of water. In the evidence of the Hooghly Enquiry of 1853, Colonel Forbes alludes to a report that the head of the Bhagirathi was closed by a sandbank 15 feet high, probably about 1780. Again in 1797 Captain Colebrooke stated that the rivers were not usually navigable throughout during the dry season, though the Bhagirathi was open throughout in 1796 for boat traffic. Some of the troubles in these early years was undoubtedly due to damage caused by trees which fell into the river, and wrecks which were not removed and formed snags. In 1819 the conservancy of the rivers was taken in hand, attention being first paid to the Matabhanga, and we know that the Bhagirathi closed in March 1824 when a sandbank formed across the entrance.

Obstructions in Bhagirathi in early years of 19th century

26. In the history of the river, Lang's report already given in page 25, it will be seen that between 1824 and 1838 the Bhagirathi never provided a depth of 3 feet throughout the dry season, except in one year 1825 and this was in spite of cuts and bandalling. The river entrance on occasions closed with less than 2 feet as early as November and in 1830 in that month, the bed in the upper portion of the river was said to be nearly level with the surface of the water in the Ganges in many places. It is a significant fact that in 1835, as so much trouble was experienced in maintaining the river channels, it was decided to give up the attempt to keep the rivers open and all works were stopped for two years. This was at a time when the maintenance of the rivers was of great importance, as they were then the chief highways of traffic connecting Calcutta with Upper India.

27. A cut through a stiff mud bar at the entrance of the Bhagirathi in 1837 appears to have effected considerable improvement and opened the channels, which provided with bandalling over 3 feet throughout the dry season of 1838. The entrance was kept with a depth of 3 feet and over till 1845, though the channels lower down provided at times only 2 feet 3 inches. Subsequently, as will be seen in statement M, the Bhagirathi frequently closed altogether again and from 1851 to 1853 this occurred by February, the river being unnavigable in the latter year by December. In these years also the least depth below the entrance was practically nil.

Obstructions in Jalangi

28. The Jalangi was kept open for small boat traffic throughout the dry season in early months of 1825, 1829, 1830, 1831 and 1834, but in the remaining years between 1824 and 1847, the channel closed sometimes as early as December.

Obstructions in Matabhanga

29. The Matabhanga was open under abnormal conditions in 1795 and again from 1809 to 1818. The closing of the Kumar offtake resulted in a depth of 3 feet being maintained throughout the season 1821-22, but for the remaining years till 1847 it was never navigable throughout the dry season below the offtake of the Pangasi river.

Obstructions in recent years

30. In the past twenty years, the rivers have not been open throughout the dry season for boat traffic on a single occasion. For the greater part of this time the Bhairab Jalangi provided the best depth and was open throughout the dry months from 1902 to 1907 with depths of only 1′-9″ and 2′-6″. For the past four years, the three rivers have had their offtakes entirely closed by sandbanks in the dry season and the Bhagirathi entrance is at present blocked by a sandbank 10 feet high, which however is not so bad as the condition about 1780, as reported by Colonel Forbes.

31. The number and obstructiveness of the sandbanks along the course of the river appear, however, to be somewhat greater now than in 1830 which was an exceptionally bad year for that period, for the Bhagirathi, when in November, there were 23 shoals with less than 2 feet depth between the entrance and Nadia, whereas in 1917 there were 25 similar shoals in the whole length of the river at the same season.

Steamer traffic in Nadia rivers

32. The waterways were in past years largely used by steamer traffic with the Upper Ganges and even with Assam *via* Goalundo, the saving in distance, as compared with the Sundarbans' route, being very considerable. The rivers are now rarely used by occasional steamers and in fact since 1915, the service by the larger Inland Steam Companies has been abandoned and the pilots withdrawn. This policy has, however, been largely dictated by economic reasons and is not entirely due to greater difficulties of navigation as is sometimes supposed. Railway competition with the Upper Ganges

districts was found too strong for the Steamer Companies, and at the same time increasing trade with the Barisal district served to divert the remaining traffic into the Sundarbans' route. The abandonment of the Nadia rivers in this respect naturally tended to foster an impression of general deterioration

33. An endeavour has been made to obtain information regarding the use made of these waterways by steamers, particularly the first and last vessels passing through each season, as this would furnish a very fair test of the increasing difficulties of navigation The records at the toll stations on the Bhagirathi and Jalangi are unfortunately not available before 1902, but in the Berhampur gauge book, entries have been made of steamers passing the station between 1861 and 1889 These entries are for the most part casual, and obviously do not in every year include all the vessels, but particular mention is made at times of the first and last steamers of the season.

34. Captain Brame of the India General Steam Navigation and Railway Company has kindly furnished a record of the vessels using the rivers since 1889 and various other useful information in this respect, and such records of the steamer traffic as are available are tabulated in statement N

35. The first mention of a steamer using the Nadia rivers, is in Branch Pilot S. Ransom's evidence before the Hooghly Commission of 1844 "On referring to my private journal of 1830, I find we left Calcutta on the 14th October 1830 in the steamer 'Hooghly' towing the 'Soonamokee' with Lord W Bentinck and suite; the steamer drew 4 feet 6 inches. On the 21st October we passed through the Jellinghy into the Ganges with nothing less than 6 feet , I observe by the reports of the Superintendent of those rivers, that no such amount of water is to be got now, so late in the season as October and November, consequently the steamers are obliged to go *viâ* the Sunderbuns, an increase of distance of 300 miles. At the date I mention, 1830, there were used at the entrances of the Bhagirathi and Jalangi, dredging boats to keep the mouths of these feeders open as long as possible, and as early too , consequently we had a longer and stronger gush of water into the Hooghly." First steamer recorded to pass through the Nadia Rivers, 1830

36. This is a good example of casual personal opinion, assuming that deterioration was general, because conditions happened to be better in a previous year with which the witness had acquaintance From Lang's report, it will be seen that 1830 was an exceptionally good year of that period for the Jalangi and large boats were able to use the river till December, but previous to this, in the years 1826, 1827 and 1828, the conditions were not so good In the past five years, 1913 to 1917, the depth of the entrance of the Bhairab at the latter end of October has varied between 3 feet 6 inches and 5 feet, which under the present conditions compares very favourably with the state of the Jalangi entrance 90 years ago

37. These rivers have apparently been alternately taken as steamer routes as one deteriorated and another improved, but the Jalangi and Matabhanga owing to their sharp bends and restricted channels have seldom or never been used for downward navigation and more use has generally been made of the Bhagirathi

38. Captain Brame states "The Jalangi was used for main line steamers proceeding from Calcutta to Goalundo or Assam during the rains from 1858 to 1866 It deteriorated about the latter date and the Matabhanga was then used and was in use when I joined the Inland Service in 1882 It was then quite a good river and in 1884 I went up with the 'Shillong,' one of our steamers towing three flats It was never used for downward traffic, being too narrow and winding It afterwards gradually deteriorated while the Jalangi improved and by 1890 it became so bad that we abandoned it in favour of the Jalangi and it has never been used since It has now degenerated into a mere gutter and will, I fancy, eventually close. In 1891 we sent our Assam main line steamers through the Jalangi There would appear to be some kind of oscillation between these two rivers, one improving while the other deteriorated We used the Jalangi from 1891 for main line steamers towing flats to Goalundo, and Assam up to 1896, but owing to increased trade with the Barisal district it was found politic to send steamers by the longer Sunderbans' route, calling at Jalakhati, Nalchiti, Barisal, etc. We continued to use the Jalangi for small craft proceeding to the Ganges districts up to 1907, from which date forward we ceased to use the river altogther. It had deteriorated somewhat like the Matabhanga and there was recently little advantage in using it as the Bhagirathi was open for any vessels proceeding to the Ganges districts and this river carried better water than the Jalangi."

39. From statement N it will be seen that before 1875, steamers frequently passed through the Bhagirathi before the end of June and sometimes even as early as the middle of that month, at times when the gauge at Berhampur was only about 43 feet above datum. This would be only 2 to 3 feet above the recent lowest stage level, but at that time it gave a rise of 6 to 7 feet above the lowest stage of the river. In recent years, the earliest vessel of large size to pass through the Bhagirathi was the SS. 'Sherani' of about 6 feet 6 inches draft, which came through on the 2nd July 1910 when the level at Berhampur had risen 12 feet 6 inches and the following year another large vessel passed through with the same rise However, in 1899 and 1912, light draft steamers passed through with a rise of 8 and 7 feet.

40. The last vessels to go through the river in recent times proceeded up at the end of September in 1904 and 1906; whereas in 1867 a vessel went through on the 12th October and in 1889 on the 8th October. On the other hand in 1865, the steamer "Bombay" with a draft of about 4 feet 6 inches had to turn back from Berhampur on the 1st October, as there was insufficient depth at the entrance. Making full allowance for the

fact that in the earlier years, the general draft of steamers was about 4 feet 6 inches, or less than at present, and further that as the rivers were then regular routes, full advantage was taken of them, that is immediately they opened until they closed, the foregoing evidence still indicates that the obstructions to navigation in the Bhagirathi in the flood season are somewhat worse now than formerly.

41. As regards the conditions in the dry season, even taking into consideration, the probable relative lowering of the low water level of the Ganges, owing to the supply now abstracted by the Ganges canals, the difficulties seem now to be greater than in the earlier half of the last century. The process appears, however, to have been extremely gradual and the very fact that even with the evidence available it is difficult to arrive at a definite conclusion, shows that the conditions cannot be generally very materially worse than they have been in the past.

42. The Bhagirathi undoubtedly in recent years has had an abnormally bad entrance, but if Colonel Forbes' statement in 1853 can be trusted this is no worse than the passing phase of 140 years ago.

43 Though the obstructions or bars in a river of the description under notice may not get progressively higher, the river may deteriorate through the extension of the shoals into the pools and a general restriction of capacity owing to increasing deficiency of supply from the main stream. However, considering that the Bhagirathi head was dry 250 years ago, that 150 years ago the river was not navigable during the dry season by boats of even 2 feet draft and that nearly 100 years ago there were in the river 23 shoals with less than 2 feet depth as early in the season as November, it is obvious that a very gradual rate of progressive deterioration should ere now have served to bring the river to a critical condition, where it would have ceased to fulfil its normal functions and have decayed rapidly. What is true of the Bhagirathi applies to the other two rivers.

Major Lang's statement, 1853

In his evidence before the Hooghly Commission of 1853, Major Lang refers to the mouth of the Bhagirathi being then closed in November and stated "The natives corroborate what I believe from Rennell to have been the fact, that 75 or 80 years ago, when the head of the Bhagirathi was near its present position, that river was obstructed annually early in the dry season to such an extent that cargoes were landed in the neighbourhood of Suti, conveyed thence by land to Jangipur and thence taken down the river in small dinghies" Furthermore, "I think within the last four years, a smaller supply of water has entered the Nadia rivers between the months of November and June than in the ten years preceding, with the exception of the year 1846-47 when the supply was decidedly less than it was in 1849-50, by the Bhagirathi and in 1850-51 by the Jalangi, at the same time I feel fully convinced that for four years subsequent to 1826, the total supply was quite as little during the dry season as it has been in any year since 1840, and I am also strongly of opinion, both from what I have heard and from what I have read on the subject, that before 1825 also there were periods when the obstructions to the influx of water were quite as great as they have ever been since In the best seasons, the quantity of water entering between January and the inundation is so very small compared to the volume of water included in the bed of the Hooghly above Calcutta, that the difference when the river is open and when it is closed would in the dry months be scarcely appreciable A discharge of 1,000 cubic feet of water per second would be sufficient to keep one of the Nadia rivers open. I have not measured at any time the quantity of water after the three have joined, but from casual observation I should say that it would be difficult to determine from appearances below Suksagar whether one or other of the rivers were open at the mouth, so great is the supply in their channels from percolation and from springs in their beds and I think that the supply of water in the Hooghly is not very greatly diminished in the dry season from the entrances of its feeders being closed"

Capt Sherwill's report, 1857

About this time, Captain Sherwill examined the whole country carefully in the course of a survey and in a report dated 1857, he discussed the general problem of changes in the deltaic river system of Bengal. He drew attention to the old red clay alluvium, and a patch of this eastward of Jangipur, he considered to have blocked the present south-easterly course of the Ganges, until broken through, probably by erosion. He found the Nadia rivers generally in such a bad state that he considered their condition hopeless.

"The process of silting up is rapidly proceeding in the beds of the Bhagirathi and Jalangi and of necessity it must continue to do so, the further the Sandheads advance into the Sea." This advance, as has been seen, is really inappreciable He states "The Bhagirathi has more than once, as is plainly shown by the old beds between Suti and Nadia, left its present bed and flowed over the country south-east from Murshidabad, mingling its waters with those of the Jalangi and Matabhanga and would, were it not for the embankment, probably leave its present bed altogether and flow through the districts of Murshidabad and Nadia and fall into the Matabhanga and Bhairab, leaving its lower course, or from Nadia to the Sea to be washed by the tides and to become a headless river similar to the Mutlah."

If the bed level of the river continues to rise, this will become a probable future contingency, but the conditions even thirty years after the above statement was made, do not appear to have been favourable for a diversion. It will be remembered the Bhagirathi was afforded an opportunity for an avulsion when the Laltakuri breach in 1885 opened to a width of half a mile and passed 50,000 cusecs for three weeks.

Finally he says "Speaking from many years' experience and knowledge of the river Bhagirathi and from having thoroughly examined the country east and west of it, I am of opinion that the river from Suti on the Ganges to Nadia at the junction of the Bhagirathi and Jalangi, *is gradually but certainly filling up*, and that it can never be made

with the means at present employed a navigable river, even for small boats, from October to June, or for nine months in the year, but that it will for many generations, if ever, be closed as an outlet for the great Gangetic freshets during the rainy season, or from June to September, I do not think possible, or probable.

If a passage for boats is required from Calcutta to the Ganges, it must be sought for, not further north of Calcutta than the junction of the Matabhanga and Hooghly rivers The Bhagirathi in its present state can never be relied upon as, or expected to be, a scourer of the river Hooghly, its water can never be looked upon as an assistance to the shipping of Calcutta, the quantity poured into the Hooghly being so very small, and although the water that used to flow down the Saraswati is now poured into the Hooghly, the river is shallower than it was a hundred years ago . . .

If the state of the river was so bad in 1666, or 190 years ago, what would it have been in 1856, had it not been taken in hand by the English, bandals erected, passages cleared of sunken trees and timber rafts, most probably it would long ago have been closed altogether and yet with all the labour and expense bestowed upon it, it still remains an *unnavigable* river for 8 months in the year.

If upon a series of levels being taken, it is proved, as is strongly suspected to be the case, that the bed of the Bhagirathi is higher than the bed of the Ganges, then must all hope of ever making the Bhagirathi a navigable river cease but if on the contrary it is proved that the bed is lower than the Ganges, then one remedy for the shallowness of the Bhagirathi remains—it is that the engineering talent at present in India and at the disposal of the Government be brought to bear upon the subject. To open this river from Calcutta to the Ganges would be a great work, it would lessen the labour, hard labour of thousands, by shortening the present tedious Sunderbands passage of boats proceeding from Calcutta to the North-West and would increase trade a hundredfold But, as before observed, the proposed series of levels would set the matter at rest for ever, but from all I have seen of the river, I feel inclined to predict that the Bhagirathi by the inevitable law of natural operations, is doomed to be a dreary bed of sand for nine months in the year."

This was over 60 years ago when, as intimated by Major Lang, there was seldom a flow of even only 1,000 cubic feet a second, required to keep any of the rivers open in the dry season

44 The general conclusion, therefore, is that the rivers pass through successive phases of deterioration and improvement and while the general tendency is probably towards deterioration, the process so far, has been very gradual and is difficult to determine definitely. General conclusion as to deterioration

45. The bed levels of all the rivers, particularly the Bhagirathi, appear to have risen very gradually in the past half century and this, though most probably compensated for to some extent by a corresponding rise of the Ganges bed level above Sara, indicates a certain measure of deterioration, at least in the Bhagirathi since 1861. There is, however, no evidence to show that the process is permanent On the other hand, the increase in the average range of stage at the entrance, which in the past 8 years was 6 inches greater and in the past 28 years, 2 feet 2 inches greater than in the fourteen years period, 1840 to 1853, shows that, whatever the causes may be, more water must have passed down the Nadia rivers recently during the flood season than during that particular early period, though probably the discharge has not been so great as before the end of the 18th century The relative lowering of the Ganges low stage level owing to the abstraction of water for canals would probably account to some extent for the greater obstruction to navigation in the dry season in the recent years. Greater discharge in recent years than in 1840-53

46. Furthermore, the opening of the modern Bhairab channel 30 years ago, which may have been a natural resultant of the raising of the Ganges bed level, is a very real gain so far as the general Nadia river system is concerned. Opening of Bhairab again in recent years

47. The methods employed in the endeavour to keep the entrances of the rivers open and to provide sufficient depth of water over the shoal crossings for boat traffic have been chiefly training works by means of bandals and spurs, and dredging Methods of improvement employed

48. The bandal system has been in use on the Nadia rivers since the conservancy was first taken in hand in 1820 and is particularly efficacious in improving the lower channels of the rivers so long as there is a sufficient flow of water to permit them to act. A "bandal" is a permeable, oblique weir, or spur, placed so as to narrow a wide shallow channel and to guide the current into the channel selected which it improves by the scour which takes place along the face of the bandals, owing to the rush of water under them The bandal used in 4 to 8 feet depth, consists of rows of plain bamboo mats, "jhamps" as they are called, each being 6 feet 9 inches by 2 feet 3 inches, which are fastened at the upper edges to a row of bamboo piles sunk 2 feet apart into the bed of the river along the selected position. The piles are bound together by a horizontal waling and are supported by struts placed about 6 feet apart on the downstream side. The jhamps are fixed so that their lower edges are about 6 inches or more above the bottom and the rush of water through this space, owing to the head created by the obstruction of the mats to the natural flow, scours away the sand at the bottom for some distance from the bandal. The sand so scoured is deposited behind the bandal and so helps to keep the flow in the channel scoured. As the sand scours under the bandal, the latter is sunk correspondingly to maintain its effect The bandals are generally placed at an angle of 45 degrees at which inclination they are presumed to have their maximum effect. The work is usually started when the depth of the river has fallen to 6 feet and though it is sometimes continued till the depth is 1 foot, the effect after the depth has fallen to 2′ 9″ is not considered worth the cost

Bandal system.

Description of bandal

General angle of bandals

Major Lang's opinion

49 Major Lang in 1853 declared that if the velocity was as great as 2 feet a second at the end of November, within the entrances of any of the Nadia rivers, he should have no doubt of being able by the use of the usual means to keep the river open throughout the season to a depth of 3 feet, and also stated that he had invariably found that with a fair supply of water, a depth of 3 to 4 feet could be gained and maintained by means of bandals, where before the maximum depth had fallen as low as 1½ to 2 feet.

Corrugated iron sheets in place of mats

Spurs

Sir Robert Hanbury Brown's paper on bandals

50. Bandals are also employed to close loop channels and to prevent the erosion of cutting banks Corrugated iron sheets have been used in place of the mats in bandals, but are not so efficacious, as the permeability of the mats is an advantage. Jungle spurs consisting of a braced double row of bamboos filled with brushwood are used sometimes at the entrances to close loop channels and to force the current into any direction required. These are not employed in the lower channels as they get buried and are likely to form obstructions later A full description of the action of bandals and spurs is given in a professional paper read by Sir Robert Hanbury Brown, K.C M.G., MAJOR, R.E., before the Council of Royal Engineers

Early attempts at dredging

Scraping

51 Dredging has been frequently resorted to in an endeavour to keep the entrances open. Dredging machines drawn by bullocks were used by Mr. May in 1823 and 1825 and later a steam dredge was tried, and though Mr. May believed at first that he could obtain very good results from these machines, he was later convinced of their ineffectiveness. This is not surprising in view of the meagre results obtained in recent years by dredgers of far superior power The only use these earlier dredgers could be put to, was to stir up the sand so that the current could carry it away If the current was weak, the sand was so loose that the sides of the dredged cut simply fell in and filled up the channel, and Major Lang considered that if there was any flow, the common bandal was just as efficacious, although by dredging above the bandal, desired results could be obtained sooner. Rake dredgers and spiked rollers were also employed to stir up the sand and open the channels, but apparently with little success Hand dredging by kodalies or hoes has been frequently resorted to and though, as Sir Robert Hanbury Brown states, work can be done in 2 feet 6 inches to 3 feet of water, the method is very expensive In order to provide a small flow of water for domestic purposes when the entrance is dry, a channel is now usually scraped through by hand, using an iron sheet

First experiment with modern dredger, "Lindon Bates"

52 The first experiment with a modern dredger on the Nadia rivers was undertaken by Mr O C Lees in April 1902 with the "Lindon Bates" belonging to the Calcutta Port Trust This vessel is a sand pump dredger of 400 I. H P with 18-inch suction and cutter, and discharges through an 18-inch pipe line She lifted in the Bhagirathi on an average about 4,700 cubic feet of spoil an hour, working 274 hours She was taken up into the Bhagirathi, having first cut through the Gayespur bar on the Upper Hooghly below Nadia, at the end of April 1902 and worked till the middle of May Mr Lees was quite satisfied with the results of the experiment and arrived at the following conclusions —

Mr O C Lees' conclusions

(i) That under the conditions which prevailed when the experiment was made, a cut made through a shoal will not fill up again, but will be deepened by the scouring action of the current through it

(ii) That the cut should be made as deep as circumstances permit

(iii) That it is not necessary to discharge the sand over the bank of the river.

(iv) That on the contrary, this sand deposited on the river bed is likely to be of use in training the current over shoals through which a channel has been dredged and will probably obviate the employment of bandals on such shoals

Dredging with "Nemotha", "Alpha" and "Rescue", small types of dredgers

53 In 1904-05 the "Nemotha", a converted dredger with 14-inch suction, was hired for five years by the Bengal Government and first set to work on the Kamalpur shoal in the Ganges and in 1905-06 on the Maricha shoal in the Bhairab river In 1906-07 a second non-propelling dredger, the "Alpha" with 18-inch suction was also set to work on the entrance of the Bhairab and in the following year the "Rescue", another converted dredger, non-propelling with 12-inch suction, was employed on shoals in the lower reaches of the river, together with the "Nemotha" These dredgers lifted on the average, quantities, varying from 1,129 to 2,839 cubic feet of spoil an hour, the least rate being that for the "Rescue" and the greatest that for the "Nemotha"

Results of dredging inappreciable

The Bhairab remained open during the seasons 1905-06 and 1906-07, but the effects of the dredging were not permanent and in 1907-08 the entrance closed and the cutting off of the head water-supply prevented any marked success by the dredgers in the lower channels of the river. In 1908-09 an endeavour was made to open the Bhagirathi entrance by dredging with the "Nemotha" and a flow of water was maintained till the end of February In 1909-10 the "Alexandra," a modern type dredger, 200 feet in length with 24-inch suction and jets and cutters, capable of lifting 10,000 cubic feet an hour, was tried for a short period at the entrance, assisted by the "Nemotha". The Faracca channel was bunded across to force the whole flow into the Bhagirathi and a small discharge was maintained which fell gradually to 48 cusecs in April The "Nemotha" dredged again at the entrance in 1910-11 and assisted in keeping the river open during the season, the minimum discharge being 655 cusecs in January, increasing to 4,165 cusecs in February, but falling again to 2,353 cusecs in April No dredging was done in 1911-12, when the discharge fell to 18 cusecs in April, but in each subsequent season 1913-14, 1914-15, 1915-16 and 1916-17, either the "Nemotha" or the "Rescue" were employed at the Bhagirathi entrance without any definite success.

54. The work has been considerably hampered owing to the delay in commencing operations each season and difficulty in making adequate arrangements for coal and supplies. It has been found impossible with one of these small dredgers to cut through the great length of shoal at the entrance owing to the limited time The dredger cannot usually start work till the middle of October, owing to the great depth, and subsequently the fall of stage is so rapid, that long before it has completed the cut, the dredger runs the risk of being locked in, owing to the channel silting. Dredging has been usually done downstream and with only one dredger, time is occupied in going over the upper cuts in order to keep a passage clear for the vessel to pass out before the level falls too low. The sand is deposited on one side and it has been found that under certain conditions, there is very little refilling of the dredged cut. No definite conclusions on the point can be come to, as with the present condition of the Bhagirathi, one dredger of the smaller type is utterly incapable of cutting through the whole length of shoal at the entrance in order to provide the flow through which is essential if a channel is to be maintained

Difficulties of dredging under present conditions.

55 Mr. C. A White, Superintending Engineer, in his report on the waterways of Eastern Bengal and Assam, stated that the dredgers were far too small to make any real impression on the Nadia rivers, much less on the Ganges Mr. Lees had come to the conclusion that as bandals needed a velocity of at least 2 feet a second to be of any use, and since this was not always possible, dredging was the obvious course to adopt He calculated that 1,000 lakhs of cubic feet would have to be dredged from the Bhagirathi shoals to make the river navigable all the year round for steamers and boats drawing 5 feet of water and that ten dredgers of the " Lindon Bates " type would be required to do the work in 100 days. He did not consider this type suitable and recommended one dredger capable of lifting 50,000 cubic feet of sand an hour This vessel should have a maximum draft of 4 feet 6 inches and should not be too large to be unmanageable in the somewhat narrow waters of the Bhagirathi This recommendation resulted eventually in the purchase of the " Foyers " which dredger, however, has so far not been employed on the Nadia rivers.

Mr C A White's opinions

Mr O C Lees' opinions

36 The Superintending Engineer, Central Circle, in July 1906 submitted plans—

Recommendation by Superintending Engineer, Central Circle, 1906

(i) for clearing a channel 80 feet wide and 8 feet deep from the head at the Faracca channel to Nadia at a cost of Rs 12,03,863 ,

(ii) for the same work with the exception that a cut is provided for through a chur about 16 miles below Faracca and certain cuts proposed in the Bhagirathi at a cost of Rs 13,31,770

57 The Chief Engineer, Bengal (Mr Inglis), criticized the proposal under the following heads —

Mr Inglis' opinions

(i) The question of time

Unless the work could be done in six weeks or two months, it would not be of much use Fourteen dredgers each capable of lifting 50,000 cubic feet of sand an hour and working 8 hours a day, would be required to do the work and the cost of the vessels would be nine lakhs each, so that the total cost would be prohibitive

(ii) The alternative estimate with proposed cuts was condemned on account of the general disturbance to the regime of the river and the large cost of acquiring land and payment of compensation

58 Mr. Inglis stated that the Nadia rivers had been in their present state for many years . they probably deteriorate in years of low and improve in years of high floods when the river is gorged and the velocity in the channel increased, as is well known to be the case in the deltaic channels in Bengal

Nadia rivers deteriorate in years of low and improve in years of high flood

59. He considered there was no possibility of canalising any of the Nadia rivers owing to the instability of the offtakes, and thought that the only possible practical means of improving the flow will be by opening the mouths of the rivers by dredging every year and operating on the lower shoals by bandals He drew attention to the necessity of working on the channels with the greatest caution and remarked "It is often said that it will be in the interests of the port of Calcutta if a large volume of water is brought into the Hooghly I am myself somewhat sceptical about this During the flood season the water coming down the Nadia rivers is heavily charged with silt and even with the increased velocity, during ebb tides it cannot be able to do much in the way of picking up more silt, unless it has dropped at slack water the silt it has brought down from the upper river During the freshets, navigation is already very diffcult on the ebb tide, and if the flood volume should be materially increased, the difficulties will be all the greater." He also alludes to the possibility of the main Ganges once again pouring down the western side of its delta should nature accept our lead and deepen the channel. This would certainly be in the nature of a catastrophe and would probably ruin the port and the city of Calcutta.

Canalization impossible owing to instability of offtakes

Mr Inglis opinion of effect on Hooghly of improvement in Nadia rivers

60. It may be noted in this connection that in 1906, Sir John Benton had remarked that the floods of the Nadia rivers are of the greatest importance so far as the Hooghly and the port of Calcutta are concerned, since they tend to keep the former open and to scour out deposits of silt brought in by the Damodar and Rupnarayan drainage channels whose outfalls are south of Calcutta , also the flood water of the rainy season helps to strengthen the ebb tide and enables it to carry out silt brought in by the flood tide.

Sir John Benton's opinion on effect of Nadia rivers floods on Hooghly

Mr F A A Cowley's opinion.

61. The Hon'ble Mr. F. A. A. Cowley (then Deputy Secretary, Irrigation Department), who has a wide and intimate knowledge of the conditions in the Nadia rivers, reviewed these opinions in a note dated 26th February 1913 and drew the following conclusions :—

(i) It is not possible to dredge the Bhagirathi so as to keep a navigable channel for the whole year, except at a prohibitive cost.

(ii) It is not desirable to do so, inasmuch as the river with increased facilities for discharging a large volume of water into the Hooghly, will carry with it much more silt into the Hooghly and probably cause deterioration in the Hooghly

(iii) It is not possible to canalize the Bhagirathi owing to the instability of the offtake from the Ganges

(iv) It is possible with one dredger with jet agitators and no cutter, capable of removing 25,000 cubic feet of sand per hour, with a properly designed suction head, powerful pumps and some 500 feet of discharge pipe, to dredge the offtake and about one or two miles of the river at the head and so considerably increase the volume of water flowing down the Bhagirathi from January to June.

(v) The "Foyers" is not a suitable dredger, it cannot cut its own flotation, without its cutters it is not an efficient machine, a properly designed plant would do this work at less cost and with greater efficiency.

(vi) The only one of the Nadia rivers it might be possible to canalize and maintain as a navigable channel is the Matabhanga with its offtake from the Ganges just above the Sara Bridge, as the Ganges has been trained to discharge its waters permanently, it is hoped through this bridge, and this is, therefore, the only point at which the Ganges has stable banks"

62. In his report on the dredging in 1913-14, as Superintending Engineer, Central Circle, Mr. Cowley, by analysing conditions of discharge for the period from 1905 to 1913 and classifying the years in their order of merit, both as regards height and duration of flood, came to a conclusion agreeing with Mr. Inglis that in years of high flood the Nadia rivers improve and in years of low flood they deteriorate He states, "following a year of high flood with long duration, the cold and hot weather discharges are improved—in other words the Bhagirathi channel has been scoured by the floods and river discharges improved, a greater fall in the water surface being available The conclusion I, therefore, arrive at is that when the monsoon has been characterized by high floods of long duration, the mouth of the Bhagirathi should be dredged—when on the other hand, the floods have been low and of short duration, the same results can be produced by the expenditure of about Rs 5,000 on bandalling It seems, therefore, that if any permanent good is to be done in years of low floods of short duration, it is essential to dredge a channel, at least five miles long from the mouth"

Improvement of Nadia rivers in year of high flood

63 A general consideration of the question and of the foregoing opinions, appears to lead to the following conclusions —

General conclusions

(1) Owing to the general conditions in the Ganges channel between the offtakes of the Bhagirathi and Jalangi rivers, which is complicated by the entrance of the Mahananda river on the opposite side, stabilizing of these offtakes would be a matter of great difficulty. Any scheme of canalizing the rivers, so as in ensure a regular supply is, therefore, if not impossible, a doubtful remedy, requiring extensive training works in the Ganges.

It may be possible with great difficulty to canalize the Matabhanga, but the advantages in this case would be chiefly as regards navigation Owing to the small proportion of the discharge carried by the Matabhanga, the flood supply of the Hooghly would not be appreciably affected, though an additional supply of about 5,000 cusecs which might be obtained during the dry season would be beneficial

(2) The bandal and spur system of training, though probably as efficacious as any similar system which does not involve considerable expenditure, cannot be relied on to ensure a flow through the entrances during the dry season.

(3) The only alternative to provide a regular flow is by means of dredging.

(4) Dredging the whole river channel from the offtakes to Nadia would need a fleet of dredgers and the expense would be prohibitive.

(5) The object desired which is to maintain the river channels so as to avoid the risk of the rivers closing, can probably be attained by dredging the entrances only to provide a flow through during the dry season. This flow with the aid of bandalling may be relied on to keep the lower channels open.

(6) Dredging the entrances will be difficult and the results uncertain, if the situation of the offtake is very unfavourable, as at present in the case of the Bhagirathi. Under these conditions, a cut would probably need to be made to give a better offtake which could then be kept clear and maintained with one dredger, whereas, at least two would now be required.

(7) Powerful and specially designed dredgers of light draft would be needed and apparently better results could be obtained by commencing early in the season and working upstream. Every care should be taken in each case to ascertain the direction of the current, sub-surface as well as surface, and the

lines of dredging should coincide with the flow, so as to work with and not against nature. The cuts should be as deep as possible in order to take advantage of the well-known law of the "attraction of water" and the cuts should be repeated, so as to help in regularizing the dredged channel.

(8) The dredging results cannot be expected to be permanent as the continually varying conditions of slope and sedimentation on a rising river induce new sets of channel conditions and the dredged cuts of the dry season will almost certainly be filled in again during the floods, so that the operations will need to be repeated each year. This is the case in the Mississippi, where the dredgers work for only about four months in the twelve, returning at the end of each flood season to remove the deterioration caused during the high water period.

Effect of Mr Lees' dredging experiment only temporary

64.- Major Hirst criticizes Mr. Lees' last conclusion on the results of the "Lindon Bates" operation on this point He deplores the absence of records regarding the location of the cuts and states that the dredged channel only lasted a short time and that the deposit removed from it never acted as a training agent. In the circumstances, Mr Lees could never have expected that the dredged cut would be maintained over the following flood season. The results of the dredging were necessarily purely temporary and confined to the conditions under which the experiment was carried out.

Channels of Hooghly proper should improve in high flood years, though deterioration may take place in the estuary

65 Messrs. Inglis and Cowley both agree that the Nadia rivers improve during years of high flood, that is the greater velocities restrict general deposit, though the silt charge is necessarily higher. Following this argument, the Hooghly channels proper, where the velocities are still greater, should also improve generally during high flood years, though with a greater silt charge, increased deposit may take place where the river widens into the estuary The improvement of the Nadia rivers so as to increase their discharges would consequently have a beneficial effect on the upper Hooghly, but if the sedimentation is increased in relation to the critical velocity, deterioration may result in the channels of the estuary However, this result is unlikely to follow on a certain measure of improvement in the feeders and the general effect on the Hooghly of improvement of the Nadia rivers up to a certain point may be anticipated as being correspondingly satisfactory

Improvement of Hooghly likely to follow on certain measure of improvement of the feeders

Possible effect of considerable artificial improvement of feeders

66 The improvement of the rivers beyond this critical point, besides causing increased sedimentation in the lower Hooghly, may conceivably involve far more serious consequences It has been pointed out that the extension of the delta on the eastern side of the Bay is now reaching a critical stage of development which may react on the conditions of debouchment of the Ganges A considerable artificial improvement of these upper spill channels may, as Mr. Inglis has pointed out, furnish avenues of escape for the Ganges from intolerable conditions of conflict with the more powerful river Brahmaputra, and they may accordingly develop until the main stream once again pours down the western side of the delta, the results of this would be difficult to foresee This contingency, however, though within the bounds of possibility, is only pure conjecture, any reliable present indications, such as the progressive increase in high and low flood levels of the Ganges above Goalundo are lacking, and limitations of time have prevented the co-ordination of such low and high flood records as exist, particularly as there is some uncertainty as to the values of the gauges in past years. On the other hand, there appears to have been a fall in range of level of the Ganges at the Nadia rivers since Rennell's time, and this would indicate that the channel below is now generally a more satisfactory conduit for its waters and would reduce the possibility of any such diversion of the main stream in the near future.

Possible diversion of Ganges main channel through Hooghly feeders if considerably improved

Diversion of Ganges main channel not likely to be a sudden avulsion

67. In any case, it is extremely improbable that any change of the Ganges course will be in the nature of a sudden avulsion If a diversion is inevitable, pressure will probably first be thrown on the outlet afforded by the Garai through country where no main river has previously issued If, as before, this fails and the upper distributaries are involved, the enlargement of these effluents will probably be a gradual process and sufficient warning will be available of the impending change

STATEMENT A.

High and Low Flood levels of Bhagirathi at Geria.

Reduced to level of Kidderpur Old Dock Sill which is 7·759 feet below Mean Sea Level.

Year.		Low Flood level.		High Flood level.		Range.	
		Ft. in		Ft in		Ft in	
1890	...	50 7		84 1½		33 6½	
1891	...	52 5		78 9		26 4	
1892	...	52 7		81 0		28 5	
1893	...	52 4		80 2		27 10	
1894	...	53 6		82 2		28 8	
1895	...	53 10	Mean 53′ 4¼″	78 3	Mean 80′ 4¾″	24 5	Mean 27′ 0.″
1896	...	57 1		77 11		20 10	
1897	...	54 10		79 5		24 7	
1898	...	53 4		81 6		28 2	
1899	...	53 1		80 9		27 8	
1900	...	55 10		79 4		23 6	
1901	...	55 8		81 5		25 9	
1902	...	56 5		78 7		22 2	
1903	...	53 10		79 3		25 5	
1904	...	54 4	Mean 53′ 10¼″	81 8	Mean 79′ 7½″	27 4	Mean 25′ 9¼″
1905	...	54 10		77 10		23 0	
1906	...	52 10		82 1		29 3	
1907	...	52 2		78 6		26 4	
1908	...	50 10		79 0		28 2	
1909	...	51 10		78 6		26 8	
1910	...	54 10		80 6		25 8	
1911	...	55 10		80 6½		24 8½	
1912	..	54 10		78 7		23 9	
1913	...	54 10		78 8		23 10	
1914	...	55 4	Mean 56′ 0″	78 9	Mean 79′ 3″	23 5	Mean 24′ 0″
1915	...	54 3		78 5		24 2	
1916	...	57 2		79 3		22 1	
1917	...	55 0		79 5		24 5	
1918	...	61 8					

Mean 54′ 4″ Mean 79′ 9½″ Mean 25′ 8½″
Mean rise of Low flood level, 32 inches Fall of High flood level, 14 inches

STATEMENT B.

High and Low Flood levels of Bhagirathi at Jangipur.

Reduced to level of Kidderpur Old Dock Sill which is 7·759 feet below Mean Sea Level.

Year.	Low Flood level.		High Flood level		Range	
	Ft in		Ft in		Ft in	
1890 ...	48 11		83 3		34 4	
1891 ...	49 11		75 4		25 5	
1892 ...	48 11		79 5½		30 6½	
1893 ..	49 11		77 9		27 10	
1894 ...	50 2		81 0		30 11	
1895 ...	50 11	Mean 49′ 7″	76 0	Mean 78′ 5″	25 1	Mean 28′ 9½″
1896 ..	48 2		74 11		26 9	
1897 ...	48 5		77 2		28 9	
1898 ...	49 11		80 3		30 4	
1899 ..	50 11		79 0		28 1	
1900	51 5		77 5		26 0	
1901 .	51 5		80 1		28 8	
1902 .	52 5		76 6		24 1	
1903 .	49 4		77 4		27 5	
1904 .	52 11		80 8½		27 9½	
1905 ..	52 5	Mean 51′ 11″	77 1½	Mean 78′ 2½″	24 8½	Mean 26′ 3½″
1906 ..	52 5		81 1½		28 8½	
1907 .	52 5		76 6		24 1	
1908 ..	51 5		78 4		26 11	
1909 ...	52 5		76 10		24 5½	
1910 ...	52 11		79 4		26 5	
1911 ...	52 8		79 6		26 10	
1912 .	52 6		75 6		23 0	
1913 ...	49 7		76 2		26 7	
1914 ...	50 11	Mean 52′ 2″	77 1	Mean 77′ 3″	26 2	Mean 25′ 2″
1915 ...	52 11		76 4		23 5	
1916 ...	52 5		77 2		24 8	
1917 ...	53 1		77 3		24 2	
1918 ...	52 8					
Mean	51′ 2″		78′ 0″		26′ 10″	

Rise of Low Flood level, 30 inches. Fall of High Flood level, 13 inches.

STATEMENT C.

High and Low Flood levels of Bhagirathi at Berhampur.

Reduced to level of Kidderpur Old Dock Sill which is 7·759 feet below Mean Sea level.

Year	Low Flood level.	High Flood level	Range	Year	Low Flood level.	High Flood level.	Range
	Ft in	Ft in	Ft. in.		Ft. in.	Ft. in.	Ft. in
1861 ...	36 6	66 3	29 9	1891 ...	39 9	65 4	25 7
1862 ..	37 0	65 7	28 7	1892 ...	39 3	67 10	28 7
1863 ...	37 0	64 6	27 6	1893 ...	40 9	66 9	26 0
1864 ...	35 9	61 2	25 5	1894 ..	40 9	69 0	28 3
1865 ...	36 3	65 2	25 11	1895 ...	41 3	64 10½	23 7½
1866 .	36 9	62 2	25 5	1896 ...	39 3	64 1	24 10
1867** ...	39 0	66 5	27 5	1897 .	38 9	66 0	27 3
1868 ...	37 0	60 6	23 6	1898 ...	39 0	68 6	29 6
1869 .	37 3	61 9	24 6	1899 ...	38 3	67 6	29 3
1870* ...	36 9	66 9	30 0	1900 ..	40 3	65 10½	25 7½
Mean ...	36 10	64 0	27 1½	Mean ...	39 8½	66 7	26 10½
1871*** ..	40 0	66 9	26 9	1901 ...	40 9	68 3	27 6
1872 ...	40 0	65 9	25 9	1902 ...	40 9	65 3	24 6
1873 ...	37 0	63 5	26 5	1903 ..	40 6	65 9	25 3
1874** ...	36 9	66 4	29 7	1904 .	41 0	68 9	27 9
1875 .	38 6	64 9	26 3	1905 ...	40 9	65 4	24 7
1876 .	37 6	64 9	27 3	1906 ...	40 0	69 4	29 4
1877 .	38 9	61 0	22 3	1907*	41 9	65 0	23 3
1878 ...	37 0	63 5	26 5	1908 .	39 3	66 1	26 10
1879*	37 6	67 0	29 6	1909 .	40 3	65 8	25 5
1880 ..	38 3	61 3	23 0	1910 ..	40 9	67 9	27 0
Mean ...	38 1	64 5	26 3½	Mean ...	40 7	66 8½	26 1½
1881 ...	37 3	65 1	27 10	1911 ...	41 3	67 7	26 4
1882 ..	37 6	61 9	24 3	1912 ..	40 9	64 5	23 8
1883 ...	37 3	60 11	23 8	1913 ..	41 0	65 1	24 1
1884 ..	36 9	64 1	27 4	1914 ...	40 3	65 4	25 1
1885*** ...	39 0	66 6	27 6	1915 ...	41 3	64 5	23 2
1886 ..	40 9	67 0½	26 3½	1916 ...	40 0	64 9	24 9
1887 ...	39 0	66 3	27 3	1917 ..	40 0	65 7	25 7
1888 ...	37 9	67 5	29 8	1918 ...	40 7		
1889* ..	37 9	67 7½	29 10½	1919 ...			
1890* ...	38 6	69 11	31 5	1920 ..			
Mean ...	38 1½	65 8	27 6½	Mean ...	40 7½	65 3½	24 8

Mean	39 0	65 6	26 6
1861-1917	Rise of Low flood level 3′ 9″		
	Rise of High flood level 1′ 4″		

Years marked with one asterisk indicate that Bhagirathi embankment breached and there was a moderate inundation two asterisks indicate embankment breached with a severe inundation three asterisks indicate a heavy breach and very severe flood

STATEMENT D.

High and Low Flood levels of Bhagirathi at Katwa.

Reduced to level of Kidderpur Old Dock Sill which is 7·759 feet below Mean Sea level.

Year.		Low Flood		High Flood		Range.	
		Ft. in.		Ft in.		Ft in	
1890	...	......		54 6½		......	
1891	...	24 7		50 3		25 8	
1892	...	23 3		51 11½		28 8½	
1893	...	24 0		51 6½		27 6½	
1894	...	24 1		54 3½		30 2½	
1895	...	25 0	Mean 23′ 10″	49 5½	Mean 51′ 10¼″	24 5½	Mean 27′ 9¼″
1896	...	22 11		48 7		25 8	
1897	...	23 2		50 9		27 7	
1898	...	24 2		54 5½		30 3½	
1899	...	23 4		53 2		29 10	
1900	.	23 10		55 4		31 6	
1901	...	24 9		52 7		27 10	
1902	..	23 7		52 0½		28 5½	
1903	..	23 10		48 11		25 1	
1904	...	24 4		53 10		29 6	
1905	...	24 10	Mean 24′ 2½″	51 9	Mean 52′ 2½″	26 11	Mean 28′ 0″
1906	...	24 1		53 8		29 7	
1907	...	23 4		48 3		24 11	
1908	..	24 7		50 10		26 3	
1909	...	24 8		54 9		29 11	
1910	...	24 7		53 4½		28 9½	
1911	...	23 7		54 4½		30 9½	
1912	...	23 10		49 8		25 10	
1913	...	26 0		53 6½		27 6½	
1914	...	25 4	Mean 25′ 1½″	51 0	Mean 52′ 2″	25 8	Mean 27′ 2″
1915	...	25 10		49 4		23 6	
1916	...	24 8		53 10		29 2	
1917	...	26 3		52 3		26 0	
1918	...	26 1					
Mean		24 5		52 1		27 8	

Rise of Low Flood level 15½ inches   Rise of High Flood level 3 inches

STATEMENT E.

High and Low Flood levels of Jalangi at Akriganj.

Reduced to level of Kidderpur Old Dock Sill which is 7·759 feet below Mean Sea level.

Year	Low Flood level.		High Flood level		Range.	
	Ft in.		Ft. in		Ft in.	
1890 ...	47 5		73 0		25 7	
1891 ...	48 3		69 7		21 4	
1892 ..	46 0		72 1½		26 1½	
1893 ...	48 0		71 1		23 1	
1894 ..	45 6		72 1½		26 7½	
1895 ..	43 9	Mean 44′ 6[illegible]″	68 2	Mean 70′ 1[illegible]″	24 5	Mean 25′ 7½″
1896 ..	42 6		67 1		24 7	
1897 ...	41 0		68 7		27 7	
1898 .	41 6		70 3		28 9	
1899 ...	41 0		69 5		28 5	
1900 ...	39 9		68 5½		28 8½	
1901 ...	40 6		69 6		29 0	
1902 ..	38 9		66 5		27 8	
1903 ...	40 6		67 4		26 10	
1904 ...	41 3		69 7		28 4	
1905 ...	42 9	Mean 41′ 2½″	66 9	Mean 68′ 5″	24 0	Mean 27′ 2½″
1906 ..	42 3		70 8		28 5	
1907 ...	42 6		68 4		25 10	
1908 ...	41 6		68 7		27 1	
1909 ...	42 3		68 5		26 2	
1910 ...	43 3		70 5		27 2	
1911 ...	42 9		70 3		27 6	
1912 ...	43 9		68 1		24 4	
1913 ...	43 3		69 1		25 10	
1914 .	44 9	Mean 43′ 8[illegible]″	68 7	Mean 69′ [illegible]″	23 10	Mean 25′ 10″
1915 ...	43 3		69 0		25 9	
1916 ...	43 7		71 0		27 5	
1917	45 0		69 8		24 8	
1918	44 9					
Mean	43 1		69 4		26 3	

Fall of Low Flood level, 10 inches. Fall of High Flood level, 8 inches

STATEMENT F.

High and Low Flood levels of Matabhanga-Churni at Hanskhali.

Reduced to level of Kidderpur Old Dock Sill which is 7·755 feet above Mean Sea level.

Year	Low Flood level Ft in		High Flood level Ft in		Range Ft in	
1890	13 9		39 11		26 2	
1891	12 6		31 10		19 4	
1892	12 6		34 3		21 9	
1893	12 6		34 7		22 1	
1894	13 0		35 10		22 10	
1895	13 0	Mean 12′ 10″	30 6	Mean 34′ 0″	17 6	Mean 21′ 2″
1896	12 6		29 4½		16 10½	
1897	12 3		31 9		19 6	
1898	13 6		36 10		23 4	
1899	13 0		35 6		22 6	
1900	11 9		35 11		24 2	
1901	12 9		34 1		21 4	
1902	13 9		29 11		16 2	
1903	13 9		30 4		16 7	
1904	14 6		36 3½		21 9½	
1905	13 6	Mean 14′ 0[illegible]″	34 9	Mean 33′ 7½″	21 3	Mean 19′ 6½″
1906	14 6		36 1		21 7	
1907	16 0		30 9		14 9	
1908	14 9		32 6		17 9	
1909	15 6		35 9		20 3	
1910	15 6		35 5		19 11	
1911	14 6		35 1		20 7	
1912	14 6		31 11½		17 5½	
1913	16 6		34 8		18 2	
1914	18 0	Mean 15′ 6[illegible]″	32 10	Mean 33′ 8[illegible]″	14 10	Mean 18′ 2½″
1915	15 0		32 5		17 5	
1916	15 0		33 5		18 5	
1917	15 6		34 0		18 6	
1918	15 3					
Mean	14′ 1″		33′ 9½″		19 8½″	

Rise of Low Flood level, 0 inches

Fall of High Flood level, 4 inches.

STATEMENT G.

Mean Monthly discharges of Bhagirathi, Jalangi and Churni in 1915.

(The upper figures in each month indicate the average discharge in cusecs and the lower figures the total discharge for the month in millions of cubic yards.)

Month	Bhagirathi.				Jalangi		Mathabhanga-Churni	
	Goria		Katwa		Punditpur		Hanskhali	
	K F	O F	K F	O F	K F	O F	K F	O F
January ..	*Nil*	*Nil*	1,050 104	600 59 5	2,910 289	1 170 116	450 44 5	600 59 5
February	*Nil*	*Nil* ...	950 85	570 51	2,780 249	825 74	390 35	460 41
March ..	*Nil* ...	*Nil*	960 95	500 49 5	2,410 240	970 93	320 32	380 37 5
April .	*Nil*	*Nil* ...	970 93	375 36	2,370 227 5	710 68	270 26	340 32 5
May ..	240 23 8	.	2,400 238	2,000 198 5	1,820 184 5	520 51 5	360 35	330 3[illegible]
June .	1,160 111 4	410 39 3	5,140 494	4,410 423	2,510 421	600 57 5	650 62 5	820 79
July .	19,770 1,961 2	26,840 2,662	58,720 5,825	42,000 4,166 5	17,140 1,700	12,840 1,274	3,140 311 5	4,100 407
August ...	51,000 5,059 2	55,450 5,101	148,000 14,681 5	86,800 8,610 5	60,000 5,952	52,000 5 158 5	5,820 577	8,000 793 5
September .	46,300 4,444 8	50,000 4,800	149,000 14,304	138,000 13,248	75,000 7,200	59,000 5,664	8,270 794	9,300 893
October	20,800 2,063 6	20,600 2,043	34,600 3,432	25,000 2,480	33,400 3,313	21,600 2,142 5	5,520 547 5	5,300 526
November .	1,820 175	1,930 185	5,800 556	4 830 464	8,670 832	5,100 489 5	2,110 202 5	2,450 235
December ..	290 29	90 8 9	2,430 241	1,240 123 5	4,500 446 5	2,000 198 5	860 85	1,000 99
Average discharge in cusecs for whole year	11,782	12,674	34,168	25,527	17,792	13,111	2,347	2,757
Average discharge, 1st June to 30th November	23,475	25,348	66,877	50,173	32,787	25,190	4,252	4,995
Total discharge in millions of cubic yards for whole year	13,868	14,839	40,148	29,910	20,874 5	15,387	2,752 5	3,236
Discharge in millions of cubic yards from 1st June to 30th November	13,815	14,830	39,292	29,392	17,395	14,786	2,495	2,933 5
Maximum discharge on any day in cusecs	67,839	78,630	188,285	164,894	84,913	64,914	6 928	10,279

Total discharge from the three rivers during the year by Kutter's formula 63,775 million cubic yds
" " " " by float method .. 48,533 million cubic yds

K F Discharge by Kutter's formula O F Discharge according to ordinary method by floats

STATEMENT H.

Mean monthly discharges of Bhagirathi, Jalangi and Churni in 1916.

(The upper figures in each month indicate the average discharge in cusecs and the lower figures the total discharge for the month in millions of cubic yards.)

Month	Bhagirathi				Jalangi		Matabhanga-Churni	
	Gora		Katwa		Punditpur		Hanskhali	
	K F	O F	K F	O F	K F	O F	K F	O F
January	*Nil*	*Nil*	1,470 146.8	680 67.5	4,410 437.5	1,720 170.5	630 82.5	840 83.3
February	*Nil*	*Nil*	850 78.9	520 48.2	5,300 491.8	1,650 153.1	715 66.3	580 53.8
March	*Nil*	*Nil*	720 71.4	380 37.7	5,170 512.8	680 67.5	550 54.5	470 47.6
April	*Nil*	*Nil*	670 64.3	330 31.7	1,000 96	530 50.9	520 49.9	430 41.3
May	*Nil*	*Nil*	420 41.7	200 19.8	*Nil* *Nil*	370 36.7	500 49.6	370 35.7
June	2,670 256.3	4,640 445.4	15,560 1,494	13,570 1,303	500 50.9	1,040 100.3	1,060 101.7	790 75.8
July	29,260 2,903	52,380 5,196	95,950 9,518	96,620 9,585	35,910 3,562	31,260 3,101	5,250 5,208	6,630 658.7
August	71,810 7,123	86,910 8,621	96,830 9,606	78,820 7,819	55,410 5,496.6	47,640 4,726	6,780 672.5	8,850 877.9
September	72,770 6,986	84,190 8,082	123,190 11,826	108,100 10,378	63,440 6,090	55,570 5,335	8,080 777.6	10,590 1,017.6
October	35,500 3,521.6	33,270 3,303.4	94,600 9,385	75,960 7,534	51,110 5,069	36,540 3,625	6,650 659.7	8,500 813.2
November	5,700 547.2	4,870 467.5	21,780 2,093	23,200 2,227	17,610 1,090.6	10,800 1,036.8	2,460 236.2	3,980 382.6
December	520 51.6	230 22.8	2,550 252.9	2,260 224.2	6,440 638.8	3,000 297.6	710 70.43	1,290 128.5
Average discharge in cusecs for whole year	18,186	22,207	37,883	33,387	20,502	15,900	2,825	3,610
Average discharge, 1st June to 30th November	36,218	44,317	74,652	66,045	37,330	30,475	5,047	6,557
Total discharge in millions of cubic yards for whole year	21,389	26,138	44,577	39,275	23,795	18,473	3,321	4,246
Discharge in millions of cubic yards from 1st June to 30th November	21,371	26,115	43,922	38,846	21,908	17,921	2,968	3,856
Maximum discharge of any day in cusecs	106,748	162,436	170,747	171,472	68,248	65,747	8,820	12,548

Total discharge from the three rivers during the year, 68,793 millions of cubic yards by Kutter's formula and 60,626 millions by float method

K F discharge by Kutter's formula O F Discharge according to ordinary method by floats

STATEMENT I.

Mean monthly discharge of Bhagirathi, Jalangi and Churni in 1917.

(The upper figures in each month indicate the average discharge in cusecs and the lower figures the total discharge for the month in millions of cubic yards.)

Month	BHAGIRATHI				JALANGI		MATHABHANGA-CHURNI	
	Gorta		Katwa		Punditpur		Hanskhali	
	K F	O F	K F	O F	K F	O F	K F	O F
January	185 18 3	*Nil* .	1,580 156 7	1,200 119	5,700 565 4	1,900 188 5	430 42 6	770 76 4
February	172 15 2	*Nil* .	1,200 107 5	720 64 5	5,300 475	1,510 135 3	430 38 5	560 50 2
March	120 11 9	*Nil*	970 96 2	700 69 4	4,500 446 4	1,000 99 2	460 45 6	490 48 6
April	160 15 4	*Nil*	620 60 9	270 25 9	3,270 314	900 86 4	450 43 2	500 48
May	180 17 9	*Nil*	2,500 248	2,670 258	840 83 3	520 51 6	280 27 8	500 49 6
June	3,780 362 9	2,910 280 3	10,300 988 8	12,000 1,152	*Nil*	810 77 8	750 72	740 71 1
July	31 000 3 075 2	33,500 3,323 2	47,000 4,662 4	48,400 4,801 3	31,200 3 095	24,800 2,460 2	4,370 43 4	5,000 49 6
August	80,000 7,936	112,000 11,110 4	121,500 12,053	109,800 10,892	62,400 6,190	54,100 5,366 7	10,180 1,012	10,300 1,021 7
September	40,600 3,8[illegible]7 6	46 500 3,546	72,600 6,969 6	73 400 7,046 4	50,000 4,800	40 300 3,869	8 080 775 7	8,380 801 5
October	21 800 2,162 5	27,300 2,708	76,300 7 569	78,700 7,807	47,000 4,662 4	41,600 4,126 7	8,770 870	8,700 863
November	550 52 8	650 62 4	23,800 2,284 8	25,300 2,429	17,200 1,651 2	15 700 1,507 2	3,000 288	3,440 330
December	*Nil*	*Nil* ...	2,450 243	2,140 212 2	5,200 515 8	3,900 386 9	600 59 5	900 89 3
Average discharge in cusecs for whole year	14,879	18 572	30,069	29,609	18,551	15,586	3,100	3,357
Average discharge, 1st June to 30th November	29,622	36,509	58,592	57,907	34,633	29,552	5,858	6,093
Total discharge in millions of cubic yards for whole year	17,566	21,030	35 440	34,877	22,798	18,355	3,318	3,502
Discharge in millions of cubic yards from 1st June to 30th November	17,342	21,030	34,527	34,128	20,398	17 407	3,061	3,070
Maximum discharge on any day in cusecs	126 460	278,841	165,824	173,352	69 798	71,777	12,954	11,918

Total discharge from the three rivers during the year, 61,556 millions of cubic yards by Kutter's formula and 56,734 millions by float method

K F Discharge by Kutter's formula O F Discharge according to ordinary method by floats

STATEMENT J.

Discharges of western Tributaries of Bhagirathi, also Kharia Nadi.

Month	Bansloi River			Jumjumkhali Nullah			Dwarka or Babla			Adjai River			Nadan Ghat river or Kharia Nadi		
	1915	1916	1917	1915	1916	1917	1915	1916	1917	1915	1916	1917	1915	916	1917
January	*Nil*	6 10	N O	*Nil*	N O	5 10	*Nil*	270 280	462 646	*Nil*	40 62	96 133	*Nil*	N O	N O
February	*Nil*	N O	*Nil*	*Nil*	N O	30 64	*Nil*	270 280	N O	*Nil*	34 35	40 51	*Nil*	N O	N O
March	*Nil*	N O	*Nil*	*Nil*	N O	*Nil*	*Nil*	N O	*Nil*	*Nil*	N O	38 69	*Nil*	N O	N O
April	*Nil*	N O	*Nil*	*Nil*	N O	*Nil*	80 92	570 1,440	*Nil*	90 95	4 4	14 20	*Nil*	N O	N O
May	*Nil*	*Nil*	80 136	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	3,270 4,911		*Nil*	1,316 3,239	*Nil*	*Nil*	N O
June	N O	500 679	180 477	N O	N O	N O	N O	6,600 11,794	4,240 8,250	N O	5,650 8,963	4,300 8,853	*Nil*	N O	N O
July	N O	1,080 2,049	1,700 2,440	N O	N O	13 27	8,550 19,017	7,800 12 894	9,360 13,810	8,570 18,784	7,860 14,537	8,200 8,418	N O		140 287
August	6,160 9,412	1,900 4,013	16,050 39,066	N O	N O	1,776 2,687	15,000 26,934	9,110 17,973	21,000 32,160	4,080 5,754	6,300 9,816	17,150 29 198	1,990 3 255	490 921	1,570 1,742
September	6,750 11,405	8 130 22,800	3,800 4,660	N O	160 329	—457 —792	8,200 12,048	13,840 19,918	9,877 19,986	6,000 9,432	17,300 50,000	6,410 14,806	3 150 3,879		745 910
October	530 072	11,000 35,970	1,660 5,072	28,000 45,290	—40 —393	214 803	2,400 7,271	20,270 39,493	20,360 34,299	1,200 2,220	16,300 27,034	11,331 32,254	N O	N O	1,585 3,112
November	56 90	1,200 2,747	4,180 14,277	N O	56 93	79 157	620 931	5,570 13,709	14,100 31,170	220 396	3,900 9 318	4,000 14,051	91 119	N O	N O
December	15 20	40 114	74 204	N O	8 15	40 42	334 420	620 825	920 1,507	N O	190 343	380 125	N O	520 655	*Nil*

NOTE.—The upper figures indicate the rough mean monthly discharges and the lower figures the maximum discharges recorded. As the discharges were taken at intervals of a week there were probably occasions when the actual discharges were greater. "N O" signifies that no observation was taken.

STATEMENT K.

Levels and slopes down to 19 chains from the Bhagirathi Entrance, 18th to 30th April 1913.

Chainage	River-level of water surface	River level of bed	Distance between sections in feet	Fall of water surface between consecutive sections in feet	Slope of water surface	Fall of bed and rise of bed	Slope in bed	Remarks
− 23	50 16	36 16		..			.	The − figures in chainage refer to the chainage upstream from pegs in the dredged channel The + figures are chainage lower down
− 9	49 94	43 94	1,400	0 22	1/6,363	− 7 78	1/188	
− 3	49 92	38 92	600	0 02	1/50,000	+ 5 02	1/119	
5	49 87	48 87	800	0 05	1/20,000	− 9 95	1/80	The + figures in slopes of bed are slopes downstream and the − figures slopes upstream
10	49 84	47 84	500	0 03	1/33,333	+ 1 03	1/776	
20	49 82	46 82	1,000	0 02	1/50,000	+ 1 02	1/980	
30	49 76	40 76	1,000	0 06	1/16,666	+ 6 06	1/165	
40	49 66	45 66	1,000	0 10	1/10,000	− 4 90	1/204	
50	49 62	40 62	1,000	0 04	1/25,000	+ 5 04	1/192	
60	49 58	48 08	1,000	0 04	1/25,000	− 7 46	1/134	
70	49 49	47 49	1,000	0 08	1/12,500	+ 0 59	1/1,645	
80	49 00	47 00	1,000	0 49	1/2,250	+ 0 49	1/2,250	
90	48 44	44 44	1,000	0 56	1/1,790	+ 2 56	1/390	High slope of water surface due to pool at bottom of shoal
100	48 39	41 39	1,000	0 05	1/20,000	+ 3 05	1/327	Ditto ditto
110	48 19	46 69	1,000	0 20	1/5,000	− 5 30	1/188	
120	48 09	45 09	1,000	0 10	1/10,000	+ 1 60	1/625	
130	48 09	46 09	1,000	0 00		− 1 00	1/1,000	
140	47 80	42 80	1,000	0 24	1/3,450	+ 3 29	1/304	
150	47 72	43 80	1 000	0 08	1/12,500	− 1 00	1/1,000	
160	47 00	45 00	1,000	0 72	1/1,390	− 1 20	1/833	High slopes due to pool at bottom
170	46 87	46 37	1,000	0 13	1/7,690	− 1 37	1/729	
180	46 69	46 03	1,000	0 18	1/5,555	+ 0 34	1/2,940	
190	46 63	26 63	1,000	0 06	1/16,666	+ 19 40	1/51	

NOTE —The above levels require an additive correction of 5 56 feet to refer them to Kidderpur Old Dock Sill

STATEMENT L.

Rainfall over catchment area of western tributaries of Bhagirathi and over Nadia area.

Year	Mean rainfall at Deoghur, Naya Dumka, Asansol and Berhampur	Mean rainfall at Rampur-Boalia, Berhampur and Krishnagar
	Inches	Inches
1887	54·73	58 32
1888	54 30	53·12
1889	51 96	48·27
1890	63 6	66 84
1891	48 94	49 59
1892	47 81	42 83
1893	69 97	73 81
1894	62 12	54·05
1895	39·04	36·21
1896	42 27	40 10
1897	54 65	52 71
1898	68 23	70 76
1899	58·85	59 05
1900	56 83	59·93
1901	42 52	51·71
1902	55 15	62 34
1903	14 51	52 57
1904	51·48	50 34
1905	56·26	77 51
1906	49 96	55 15
1907	42 38	40 30
1908	46·21	45 97
1909	58 87	66 35
1910	51 95	55·43
1911	56 88	60·10
1912	45 94	48·65
1913	67·12	73·61
1914	53 81	64 50
1915	46 31	59 57
1916	64·78	71 48
Mean	53·5	56 7

STATEMENT M.

Depths in Nadia Rivers during dry season and flood months and rise of river at entrance from 1840 to 1853 by Major Lang.

Name of river	Year.	Dry season. Least depth at entrance		Dry season. Least depth below entrance		Flood season. Greatest depth at entrance.		Flood season. Greatest depth below entrance		Total rise of river at entrance.		Remarks
		Ft	In	Ft	In	Ft	In	Ft.	In	Ft	In	
Bhagirathi	..	3	0	2	3	32	3	33	0	...		No gauge erected till 1846, Jalangi closed in April
Jalangi	1840	0	0	1	5	25	3	21	9	26	0	
Matabhanga		0	9	0	6	24	0	26	3	...		
Bhagirathi	..	3	4	2	6	23	6	23	0	...		
Jalangi	1841	1	6	1	0	18	10	18	10	22	6	
Matabhanga		1	8	1	6	22	0	19	9	...		
Bhagirathi	..	3	9	2	6	21	0	21	6	..		Jalangi unnavigable in February, Matabhanga closed in March
Jalangi	1842	0	2	0	3	20	6	20	6	20	0¼	
Matabhanga	..	0	11	0	7	21	9	24	0	...		
Bhagirathi	...	3	3	2	5	21	0	19	6	.		Jalangi closed in January, Matabhanga in February
Jalangi	1843	0	0	0	3	22	3	21	3	20	8	
Matabhanga	...	0	0	1	0	21	6	23	3	..		
Bhagirathi		3	0	2	3	22	6	25	0	...		Jalangi and Matabhanga closed in February
Jalangi	1844	0	0	0	4	29	0	28	6	27	1½	
Matabhanga	...	0	0	0	3	27	0	29	0	...		
Bhagirathi	.	3	4	2	3	19	6	19	6	..		Jalangi and Matabhanga closed in December
Jalangi	1845	0	0	0	6	26	5	26	0	24	5	
Matabhanga	.	0	0	0	7	24	0	26	0	.		
Bhagirathi	.	2	5	2	3	18	0	19	0	.		Jalangi closed December, Matabhanga in November
Jalangi	1846	0	0	0	10	30	0	28	0	24	3½	
Matabhanga		0	0	1	2	27	6	28	0			
Bhagirathi	.	0	6	1	3	40	0	23	0			New entrance opened in Bhagirathi, Bhagirathi and Jalangi unnavigable and Matabhanga closed in January
Jalangi	1847	1	9	0	11	28	10	29	0	28	7	
Matabhanga	.	0	0	0	9	21	3	26	0	.		
Bhagirathi	.	3	0	2	0	23	0	19	0	..		Matabhanga closed in February
Jalangi	1848	3	2	2	6	22	3	22	3	26	2¼	
Matabhanga		0	0	0	3	21	3	24	0			
Bhagirathi	...	2	0	1	6	20	0	16	0	.		Jalangi unnavigable in February, Matabhanga closed in November
Jalangi	1849	0	5	0	3	21	0	21	0	24	9¾	
Matabhanga	.	0	0	1	5	17	6	22	6	...		
Bhagirathi	..	3	0	2	6	20	0	17	6	...		Ditto ditto
Jalangi	1850	0	3	0	3	29	0	20	0	23	0	
Matabhanga	.	0	0	0	8	22	0	21	0	...		
Bhagirathi	..	0	0	0	4	12	0	10	0	...		Bhagirathi closed in February, Matabhanga unnavigable in February
Jalangi	1851	5	0	2	8	28	0	21	0	21	7¾	
Matabhanga	.	0	2	0	3	22	6	16	0	...		
Bhagirathi	...	0	0	0	2	18	0	16	0	...		Bhagirathi closed in February, Matabhanga unnavigable in January.
Jalangi	1852	3	9	2	0	26	0	27	3	22	11¾	
Matabhanga	..	0	3	0	3	24	0	20	0	...		
Bhagirathi	...	0	2	0	3	14	6	14	0	...		Bhagirathi unnavigable in December, Jalangi closed in February, Matabhanga unnavigable in April
Jalangi	1853	0	0	0	5	22	0	24	9	20	0¼	
Matabhanga		0	3	0	5	18	9	17	6	...		
								Mean		23	6	

STATEMENT M.

Depths in Nadia Rivers and rise at entrance of Bhagirathi, 1903 to 1917.

Name of River	Year	Dry season: Least depth at entrance Ft	In	Dry season: Least depth below entrance Ft	In	Flood season: Greatest depth at entrance Ft	In	Flood season: Greatest depth below entrance Ft	In	Total rise at Gena Ft	In
Bhagirathi		0	3	0	6						
Bhairab-Jalangi	1902 03	3	6	1	9					25	5
Matabhanga		0	2	0	6						
Bhagirathi		0	0	0	1						
Bhairab-Jalangi	1903-04	3	3	1	9					27	4
Matabhanga		0	0	0	3						
Bhagirathi		0	0	0	6						
Bhairab-Jalangi	1904-05	3	3	2	0					23	0
Matabhanga		0	0	0	4						
Bhagirathi		0	0	0	7						
Bhairab Jalangi	1905-06	3	0	2	6					29	3
Matabhanga		0	0	0	3						
Bhagirathi		0	0	0	5						
Bhairab-Jalangi	1906-07	2	9	2	6					26	4
Matabhanga		0	3	1	0						
Bhagirathi		0	3	0	8						
Bhairab-Jalangi	1907-08	0	9	0	9					28	2
Matabhanga		0	0	1	0						
Bhagirathi		0	3	0	6						
Bhairab Jalangi	1908 09	0	9	0	9					26	8
Matabhanga		0	0	0	6						
Bhagirathi		0	4	0	3						
Bhairab-Jalangi	1909 10	0	6	0	6					25	8
Matabhanga		0	3	0	6						
Bhagirathi		2	0	0	11						
Bhairab-Jalangi	1910-11	0	6	0	6					24	8½
Matabhanga		1	0	0	6						
Bhagirathi		1	0	1	0						
Bhairab-Jalangi	1911-12	0	9	0	9					23	9
Matabhanga		0	0	0	5						
Bhagirathi		1	0	1	0						
Bhairab-Jalangi	1912-13	0	6	0	6					23	10
Matabhanga		0	0	0	5						
Bhagirathi		0	6	1	0	18	0	19	8		
Bhairab-Jalangi	1913-14	0	9	0	0	22	0	21	0	23	5
Matabhanga		0	6	0	6	17	6	17	0		
Bhagirathi		0	0	0	3	21	0	19	6		
Bhairab-Jalangi	1914-15	0	9	0	6	20	9	16	6	24	2
Matabhanga		0	0	0	6	21	0	20	0		
Bhagirathi		0	3	0	3	15	0	18	0		
Bhairab-Jalangi	1915-16	0	6	0	6	17	0	19	0	22	1
Matabhanga		0	0	0	6	13	6	15	0		
Bhagirathi		0	3	0	6	16	0	20	0		
Bhairab-Jalangi	1916-17	0	3	0	6	22	0	21	0	24	5
Matabhanga		0	0	0	6	13	0	16	3		

Mean 25'-2½"

STATEMENT N.

Showing approximate dates when steamer service through Bhagirathi opened and closed.

Compiled from casual record kept in Berhampur Gauge book.

Year	First steamer passed Berhampur	Last steamer passed Berhampur	Gauge level at Berhampur above K D S First	Gauge level at Berhampur above K D S Last	Remarks
			Ft In	Ft In	
1861	No mention ...	No mention ...	...	...	
1862	4th July, up ...	2nd August ...	46 10		Eleven steamers passed through
1863	26th June, up ...	*Nil*	43 0	...	One steamer passed Gauge fell to 42 feet on 29th June
1864	*Nil*	*Nil*	...	.	
1865	15th June, up	21st June, down ...	43 5	47 3	1st October, Steamer *Bombay* had to turn back on account of insufficient depth, gauge 55 feet 6 inches, 3 steamers
1866	25th June, up ..	25th June, down ...	43 2	43 2	Two steamers
1867	11th September, up	12th October, down ...	63 4	57 2	Three steamers, 8th October, steamer reported 6 feet at entrance, Gauge at Berhampur 59 feet 2 inches
1868	21st June, up .	*Nil*	48 7	...	One steamer
1869	30th June, up ..	30th June, down	45 2	45 2	Two steamers
1870	5th July, up .	*Nil*	51 3	..	One steamer
1871	14th June, down ..	*Nil*	44 7		One steamer (*Bombay*)
1872	3rd July, up .	*Nil*	50 7	.	One steamer
1873	15th July, up	22nd September .	50 0	62 3	Three steamers
1874	21st June, up .	July . ..	45 0	..	Six steamers
1875	No mention ..	.. .	...	...	
1876	No mention .	.... .	...		
1877	26th August, up ...	....	56 2		Government steamer *Peel*
1878	No mention .	......	...	...	
1879	5th September, up ...	26th September, up ...	64 9	62 0	Two steamers
1880	27th July, up .	.....	58 3	..	One steamer
1881	No mention ...	......	...	...	
1882	18th August, up ...	. ...	61 9	.	One steamer
1883	10th August ...	... .	60 2	...	Government steamer towing *Rhotas* Entrance was dry on 22nd March
1884	No mention .	......	...	...	
1885	No mention ...	.....	...	...	
1886	30th June, up ...	September ...	52 2	...	Twelve steamers
1887	11th July, down ...	August ...	52 0	...	Five steamers
1888	8th July, up ...	......	48 11	..	One steamer
1889	1st July, up ...	8th October, up ...	53 0	57 9	Three steamers, Katwa service commenced 2nd July, Azimganj service 8th July.

STATEMENT N.

Showing approximate dates when steamer service through Bhagirathi opened and closed.

Compiled from Statement furnished by Captain Brame.

Year	First steamer	Last steamer	Gauge at Berhampur First	Gauge at Berhampur Last	Remarks.
			Ft In	Ft In	
1890	6th July, up .	4th October, down ...	57 3	63 0	
1891	23rd July, up .	29th September, down	55 0	59 0	
1892	13th July, up ..	25th September, down	52 3	62 3	
1893	4th July, up ...	20th September, down	58 0	65 9	
1894	4th July, down .	9th October, down ..	58 0	65 0	
1895	....	...	54 3		River reported open 2nd July
1896	..	...	49 6		River reported open 6th July
1897	No mention ...		...	.	
1898	No mention		...	...	
1899	22nd June, up	.	46 3		Light draft steamer, 3 feet
1900	22nd July, up	. .	54 6	.	
1901	22nd July, down ...	. ..	52 0	...	
1902	29th August ..	13th September ...	57 9	63 3	Light draft, 3 feet
1903	5th July, down ...	6th August .	45 0	56 3	River not properly open Light draft
1904	8th July .	29th September ..	53 9	57 3	
1905	8th July .	30th August ..	50 6	64 6	
1906	28th July ..	27th September ...	61 3	59 9	
1907	28th July	19th September ...	57 6	58 0	Light draft
1908	9th August .	28th September ..	62 3	55 3	Light draft River reported open 5th July
1909	21st June .	21st September .	51 6	62 0	River reported open 1st July First Steamer light draft Steamer left Calcutta 22nd September, but had to return
1910	2nd July	23rd September	53 3	62 9	1st steamer S S *Sherani* Main line vessel 6 feet 6 inches draft
1911	23rd July ..	Ditto	53 9	67 3	Both main line large steamers 6 feet 6 inches draft
1912	5th July ..	16th September	47 3	63 3	Light draft
1913	26th July ..	12th August ...	57 3	63 3	River closed 31st August First light draft Last main line vessel
1914	11th July .	......	50 3		Launch River reported open July 13th
1915	*Nil* ..	... ..	..	.	Inland companies' pilots withdrawn
1916	*Nil* ..	.. ..	...	..	
1917	14th July ...	20th September ...	55 0	61 0	
1918	......	......	...	...	

CHAPTER V.

The Hooghly from Nadia to Calcutta.

Four sections of Hooghly river

THE Hooghly proper may be divided into three main sections—

(i) the Upper Hooghly from Nadia to Hooghly, a distance of 60 miles,
(ii) the Lower Hooghly from Hooghly to Kantabaria at the head of the estuary, 78 miles; and
(iii) the estuary from Kantabaria to Saugor, 36 miles *

Beyond Saugor the sands project 43 miles into the sea, to the Sandheads at the head of the Bay of Bengal and the approach channels between these sands, into the river at Saugor may be included in a fourth section.* *

Upper Hooghly Unstable regimen from Nadia to Chinsura
Fixed regimen from Chinsura to Calcutta

2. The Upper Hooghly from Nadia to Hooghly, has an unstable regimen and wanders through a wide strip of diara land continually, though gradually, changing its course. The regimen becomes fixed in the Lower Hooghly, where the channel is confined between permanent banks and erosion practically ceases, except at certain exposed positions In this chapter the Upper Hooghly and the upper section of the Lower Hooghly from Hooghly to Calcutta will be considered together.

Kharia Nadi
Kunti Nadi
Saraswati Nadi

3. The Matabhanga enters the Upper Hooghly near Chakdaha on the left bank and one unimportant tributary, the Kharia Nadi, draining the district west, north and east of Burdwan between the Damodar and Ajai rivers, flows into the Hooghly on the right bank near Mirzapur above Kalna. The Kunti Nadi, an old channel of the Damodar river, enters on the right bank at Noaserai and a relic of the old Saraswati river still exists in a khal at Tribeni These two channels are dead, the Hooghly water backing into them during the freshets and pouring out again as the level falls

Comparison of surveys of Upper Hooghly

4. There is an almost complete absence of information regarding the section of the Upper Hooghly between Nadia and Bansberia just above Hooghly The latest survey of the river channel is the Revenue Survey of 1849—55, since when the river has in places changed its course considerably, as will be seen on map No 4 showing the river about 1855 as compared with the approximate course according to Rennell and a rough sketch of its present channel

Tidal limit
Rise of tide at Nadia

5 The river is tidal throughout during the dry season During ordinary spring tides in the dry season, a flood current is perceptible as far up as Samudragarh, about 7 miles below Nadia, and in the highest spring tides of the year a slight upward current is sometimes felt at Nadia During maximum tides, the level rises and falls 2 feet at Nadia, or rather at Swarupganj in the Jalangi, half a mile higher up, and a tidal rise and fall is experienced as far up as Rajapur, 8 miles up the Bhagirathi

Gorging up of Upper Hooghly in spring tides
Tidal influence in freshets

6. Owing to the gorging up of the Upper Hooghly in spring tides, the mean water-level at Nadia is raised as much as 3 feet above the level during neap tides and this influence is felt as far up as Dadupur, 16 miles up the Bhagirathi, and also above Krishnagar and probably as far as Punditpur in the Jalangi During the height of the freshet season, tidal influence ceases above Guptipara owing to the raised level of the river, but the limit varies naturally with the height of the freshets and the strength of the tides.

Slopes of Upper Hooghly
Freshet slope

7 The slope of the Upper Hooghly during freshets on the 14th August 1916 was 3·35 inches per mile, between Nadia and Kalna, 21¼ miles, the maximum slope at low-water decreased gradually to 3·2 inches between Kalna and Guptipara, 6¼ miles, and then to 2·13 inches between Guptipara and Balagarh, 7½ miles, From Balagarh to Dumardaha, 14½ miles, the maximum slope increased to 3·5 inches and then suddenly to 6·3 inches per mile between Dumardaha and Gauripur opposite Hooghly, a distance of 10¼ miles From Gauripur to Palta, 9¼ miles, the maximum slope fell to 4 inches per mile, and became normal again at 3·2 inches per mile beween Palta and Kidderpur

Dry season slopes in springs and neaps

8 In the dry season the maximum slope of the river surface varies considerably, being naturally greater in spring tides than during neaps. At high spring tides on the 25th March 1917, the maximum fall from Nadia to Dumardaha on the ebb was about 1 inch per mile, this rate increased to 3 inches between Dumardaha and Gauripur and then fell to 2·3 inches per mile between Gauripur and Palta and 2·1 inches per mile between Palta and Kidderpur During neaps on the 4th March 1917, the maximum slope generally was approximately 1 inch per mile.

Abnormal increase of slope between Dumardaha and Chinsura
Flattening of slope indicates a raised section from Kalna to Dumardaha

9 The curious relative flattening of the slope between Kalna and Dumardaha and the sudden declivity in the fall from Dumardaha to Chinsura, which cannot be attributed to the influence of the Matabhanga entering the Hooghly below Balagarh, points to the existence of abnormal conditions in this section. This "hump" in the slope might indicate a general raising of the tract of country through which the river flows between Kalna and Dumardaha. If predisposed to the theory of tectonic movements, this elevation may very easily be ascribed to a local seismic upheaval, and though this conflicts with Major Hirst's view of a depression in this region, it would open the way to a similar field of conjecture. As a matter of fact, Dr. Muir, of Kalna, who has already been mentioned by Major Hirst, is inclined from a casual consideration of the question with reference to the incidence of malaria, to the view that the country

* Map No 7
** Map No 6.

round about Kalna is gradually rising. One of his chief reasons for this opinion is that the water-level in the tanks of the district is generally lower now in the dry season than formerly. It will be recognised that this question of tank-level is bound up with the general one of the level of subsoil water which may vary for many reasons, and it is improbable that any tectonic movements would produce visible effects so rapidly as to be detectible in the very few years under notice. View that district round Kalna is being gradually raised as tank-level is falling

10. Now in turning to a consideration of the ordinary natural agencies which are at work in this section of the river, an apparently satisfactory cause for this important abnormality becomes immediately apparent. From what has already been said, it will be recognized that the section from Kalna to Dumardaha, and particularly the middle portion from Guptipara to Balagarh where the slope is least, is the "tidal head" of the Hooghly river during the freshet season. The downcoming current surcharged with silt here meets the tide, the velocity is checked for a portion of each day, the level is raised by backing up action at high-water and general deposit takes place over the diara from overflow. The action would probably have been accentuated by the backing up effect or floods in the Damodar when the Noaserai channel was open. Natural agencies at work. Raised section the "tidal head" of the Hooghly. Deposit occurs at meeting ground of tide and freshet current

11. The effect of the gradual relative raising of this portion of the country is an interesting matter for speculation. If unimpeded and progressive it might eventually force the Upper Hooghly eastward and probably into the Ichhamati channel and the anticipated entry of the Damodar at Kalna, if not prevented, may even now cause the diversion catastrophically. This brings us to a point on which, as will be seen later, great stress is continually laid and that is the crucial question of improving the tidal flow of the Hooghly. The improvement of the tidal flow connotes an improvement of the upper channels, an improvement which can only be naturally maintained for any time by this means. An improved channel will move the "tidal head" higher up the river and so relieve the situation and it will also minimise overflow. If with the entry of the Damodar, its water can be kept in the present Hooghly course, this should effect a natural improvement of the channel through this raised section. This section, therefore, though far above the navigable Hooghly, is of the utmost importance in the maintenance and improvement of the channels of the latter and should have a prominent place in any general scheme of Hooghly river improvement. Eventual effect if process develops uninterruptedly. Great importance of tidal action. Importance of Kalna-Dumardaha section on Hooghly regiment

12. In the river channel between Nadia and Chinsura, there are now 12 bars with less than 6 feet depth at lowest low-water: of these 7 are situated below Kalna and 5 above it. In the section below Kalna, the shallowest bar with 2 feet reduced depth is just below Guptipara and over this at high-water ordinary spring tides in the dry season 7 feet 6 inches of water would be available. There are three other shallow bars, one at the crossing above Bhaira and two below Balagarh above the entrance of the Churni; these would afford 9 feet to 9 feet 6 inches depth at high-water spring tides. Between Nadia and Kalna, the worst bar is situated above the first bend about 3½ miles below Nadia and this would give only about 5 feet depth at high-water spring tides at the height of the dry season, while the second bar at Mirzapur near the entrance of the Kharia nadi would afford 6 feet. The remaining three bars would give depths varying between 7 and 8 feet at high-water ordinary spring tides. During neap tides at the height of the dry season, even at high-water, the bar below Nadia practically blocks all traffic of over 3 feet draft and Hoare, Miller's steamer service to Nadia is then consequently suspended. This bar has apparently been bad for about three years. Shoals or bars in Upper Hooghly. Bar near Ghollapara blocks traffic of over 3 feet draft during neaps

13. In the remaining portions of the channel the depths are ample and, in the bends, depths from 30 to over 40 feet are obtainable, and in one place at the Kaliganj loop, where erosion is active, the bed has scoured down to nearly 70 feet. This loop has narrowed considerably and worked downstream bodily for about 1½ miles since 1855. Fergusson, in 1863, referred to the erosion which was then taking place as indication of the activity of the Matabhanga, which he thought threatened to cut a new channel for the Upper Hooghly to the eastward of Calcutta, but was prevented doing so by the Eastern Bengal Railway embankment. A cut through the neck of this loop at Jirat might be considered. As it is in the tidal area the "cut off" may, on the whole, be beneficial by assisting the tidal flow in the Upper Hooghly and at the same time it will prevent the loop working down into the old Jabuna channel. Kaliganj loop. Fergussons' anticipations. Artificial cut at Jirat

14. There are, as already stated, no surveys of the river bed of the Upper Hooghly and the only means of ascertaining whether deterioration has occurred is by an examination of the behaviour of the tidal wave from such records as are available. This will be considered later in a general examination of the Hooghly tides. However, it is known that when the *Lindon Bates* went to the Bhagirathi in April 1902, she had to cut her way through the Gayespur and Ghollapara bars. Her draft was lightened to 5 feet 9 inches and a survey of the Gayespur bar gave 3 feet 9 inches at low-water neap tides, which reduced to the datum already used would be about 3 feet, and the Ghollapara bar afforded probably 2 feet 6 inches. The condition in 1902 was, therefore, better than it is at present. State of Upper Hooghly in April 1902

15. In the upper section of the Lower Hooghly between Hooghly and Calcutta, where the regimen is fixed, the first and most serious bar is at the crossing opposite Chinsura where the present depth is only about 3 feet below the local datum which is .5 feet above Kidderpur Old Dock Sill. At high-water in neap tides at the height of the dry season, the available depth is barely 6 feet, while at high-water ordinary spring tides, about 14 feet is available. There are two 13 feet bars at the crossings at Ichhapur and at Barrackpur, otherwise the depth in the channel is greater than 18 feet, and in places in the bights the depth falls to 60 feet. Bars in upper section of Lower Hooghly. Chinsura bar

Causes of Chinsura bar.

16. The height of the bar at Chinsura is due entirely to the present unfavourable local conditions. The contraction of the river channel at the Hooghly Bridge has been accentuated by the deposit of large masses of stone to protect the piers of the bridge. Below the site, the river widens considerably in a straight reach where the stream is not guided into any particular line of channel, with a consequent general shallowing over the whole cross section. An island occasionally forms in the river opposite Chinsura as in 1884 and 1896 and under those circumstances the restricted channel provides a better depth than in the present conditions. The Ichhapur bar appears below a sharp bend after which the river widens, and where the crossing is not well defined; and the Barrackpur bar practically reproduces the conditions of the Moyapur bar in the Lower Hooghly. In this case, the river at the lower end of the reach widens considerably and the right bank below Serampur trends away, so that the ebb stream loses its guiding control across to the opposite bank. In spite of those two obstructions, the river channel generally from Calcutta up to Chinsura is actually in good condition.

Causes of Ichhapur and Barrackpur bars.

Good condition of river from Calcutta to Barrackpur.

Deep draft vessels able to proceed as far as Barrackpur

17. There appears to be a general misapprehension that because ocean-going vessels do not go above Calcutta, the river is incapable of carrying them above the port. As a matter of fact, the channel from Calcutta to just below Barrackpur offers no serious obstruction to deep sea traffic and the largest vessels visiting Calcutta could, so far as depth is concerned, proceed up to Barrackpur with even less difficulty than is experienced in the passage up to Calcutta Above Barrackpur, even during the dry season, vessels of about 20 feet draft could navigate as far as Chinsura at high-water ordinary spring tides and the Barrackpur and Ichhapur bars, which are the only serious obstructions, would probably yield more readily than the Eastern Gut and Moyapur bars to dredging, so that with proper treatment, if necessary, the depth in this section could be materially increased. However, the narrowing width of the channel would restrict the size of vessel which, moreover, have no reason to proceed beyond the present terminal port.

Fergusson on condition of upper section of Hooghly

18. In his note on "Recent changes in the Delta" written in 1863, Fergusson alludes to the apparent inability of the upper section of the Hooghly to carry as deep traffic as formerly. He states: "For a century after 1634, when our ships were permitted to enter the Ganges, Satgaon or Hooghly was the port of Bengal and continued to be so till superseded by Calcutta"

19 "The ships of those earliest days were no doubt much smaller than those afterwards introduced, but no sea-going vessel could well now get so far up the river, and it may also be remarked that when Admiral Watson attacked Chandernagore in 1757 he took up to that city what were then called line of battle ships, vessels of 60 or 64 guns which, whatever their tonnage may have been, would with difficulty reach Calcutta now without the aid of steam"

20 As this argument supports the theory of deterioration of the river and has without doubt influenced, in a subtle manner, judgment on the Hooghly, it will be of interest to examine it in detail.

Examination of Fergusson's statement

21. Reference has already been made in paragraph 24, page 16, to the deteriorated condition of the upper section of the Hooghly in 1565, so that the larger ships, even of that time, could not proceed above Sibpur and only small vessels went up to Satgaon. This was probably due to the diffusion of the supply through the three branches of the Bhagirathi, viz, the Saraswati, Hooghly and Jabuna When the other branches decayed, and the discharge was concentrated in the Hooghly channel, this must naturally have improved.

Admiral Watson's attack on Chandernagore in March 1757

22. The available records of Admiral Watson's enterprise in 1757, from which conclusions have been loosely drawn by Fergusson and others, affords us an opportunity of comparing the earliest reliable data of the Upper reaches of the Hooghly with present-day conditions. Admiral Watson's squadron comprised the 60-gun line of battleships *Kent* and *Tyger* with the *Salisbury* (50 guns), attended by the Sloops *Bridgewater* (20 guns) and *Kingfisher* (12 guns). From the logs of these vessels, extracts from which were made by an old pilot, Mr. R. F Barlow, who served under Captain Lloyd in 1840-41, and spent a great portion of his leisure after he retired, in delving into old records concerning the Hooghly, it appears that the main squadron arrived at the entrance of the Hooghly on the 9th December 1756, H. M. S. *Cumberland* (70 guns) having grounded on Palmyras shoal and put back to Vizagapatam leaking. Kedging and towing the squadron reached Fulta on the 14th and 15th December, where they were joined by the *Salisbury* and *Bridgewater*. The *Tyger's* draft was 19 feet 8 inches and the *Kent*, after taking her guns on board, drew apparently 19 feet 6 inches

23. They moved up to Moyapur on the 29th, where the *Kent* landed two guns to assist Colonel Clive in attacking Budge-Budge fort. Then, according to the *Tyger's* log: "December 30th, engaged Bougia Bougia fort. December 31st, demolished it and dropped up the river."

(No mention is made of seaman Strahan's exploit in capturing the fort that morning single-handed, while intoxicated, as described by Ives, Surgeon of the *Kent*.)

After taking Tanna fort in Garden Reach on the way up, old Fort William at Calcutta capitulated after a slight engagement on New Year's Day, 1757. The *Bridgewater* and *Kingfisher* were sent up the river, to attack the Nawab's fort at Hooghly. This they captured as laconically recorded in the *Bridgewater's* log: "January 11th, attacked and took and burned Hooghly fort."

24. The *Kingfisher's* draft according to her log was 11 feet 8 inches forward and 11 feet 2 inches aft, and the *Bridgewater* probably drew 14 feet. The former vessel was sent up from Hooghly, but apparently had not got far, perhaps to Bansberia, when sending

her boat to sound she could not find water to float her and so dropped down to between the Portuguese Church at Bandel and the fort which was just below the present site of the Jubilee Bridge.

25. It would have been full moon on January 5th, 1757, assuming the tides were about the same as at present, there would have been about 7 feet rise at high-water at Bandel. This would mean that there could not have been more than 8 to 9 feet, if as much, on the Bansberia bar, which is about the same depth as at present. On the 10th January, when presumably the two vessels passed Chinsura, the rise of tide at high-water would have been 9 feet 6 inches, so that the Chinsura bar must have had at least 8 or 9 feet depth where there is now only about 5 feet, so this locality has deteriorated, but as explained, this would probably be due to local causes.

26. On March the 14th, Admiral Waston decided to attack Chandernagore and, according to the journal of Edward Ives, Surgeon of the *Kent*: "As soon as everything was in readiness on board the fleet and the ships cleared of their superfluous stores, they also moved up the river with the flood tide" This would indicate that the vessels were lightened and probably their drafts would not have exceeded 18 feet. The *Kent*, *Tyger* and *Salisbury* apparently crossed Barrackpur bar, or Charnock shoal as it was then called, on the afternoon high-water, first of spring tides of the 17th March with about 8 feet rise, and Ichhapur bar, or, as it was called, Banca Bazar shoal, at high-water on the afternoon of the 18th with a rise of about 9 feet, presuming the tides have not materially changed The *Kent* and *Tyger* anchored below Chandernagore on the 19th, where the *Bridgewater* and *Kingfisher* had already arrived, and the *Salisbury* joined the squadron the next day. After some preparation, at 6 A.M. off the 23rd March 1757, the vessels weighed anchor and, passing inshore of three ships which had been sunk to block the channel, opened the attack. The *Kent* and *Tyger* anchored abreast of the fort, while the *Salisbury* could not get into position to engage. According to the *Kent's* log —

"March, 23rd, 1757, 9-15 A M. The enemy hoisted a flag of truce Employed getting the ship warped into a more advantageous berth for engaging. Lieutenant Porreau and 18 men killed, myself and 46 more wounded. 4-30 P.M., His Majesty's colours were hoisted at the fort under a salute of 21 guns"

On April 1st the *Kent* weighed and dropped down to Shamnagar

"April 2nd, weighed and dropped down to the French gardens (Gourhati) and anchored in 4 fathoms, carried out 2 warps—one of 3 hawsers bent to the stream anchor and the other of two hawsers bent to the kedge—to warp over Banca Bazar shoal (Ichhapur bar)"

"April 3rd Weighed and warped—but the wind being strong the warp broke and the ship grounded."

"April 4th Got afloat, slipped the best bower and warped over the shoal, dropped down, and at 6 P M anchored below the Danes Factory (Serampur). Employed laying out warps to get the ship over Charnock shoal."

"April 5th, 2-30 P.M. Weighed and warped across 6-30 P M, anchored in 6½ fathoms."

"April 6th. Weighed and dropped into Barnagull (Barnagur) Reach, anchored in 7 fathoms, carried out the stream anchor and 5 hawsers to warp over the shoal and at 5-30 P M. moored off Calcutta"

27. It would have been full moon on the 4th April, and on the 3rd when the *Kent* attempted to cross Ichhapur bar there would have been a rise at high-water of about 8 feet. On the 4th when she crossed, high-water would have been 9 feet 6 inches. On the 5th April she waited till high-water, which would have been about 10 feet, to cross Barrackpur bar. When she warped across Barnagur shoal on the 6th, high-water would have been 12 feet. Now the *Kent* and *Tyger* were the largest ships that had ever been up the river The draft was 19 feet 6 inches before arriving at Calcutta and even though they had probably been lightened, it was apparently recognised as a risk to take the vessels so far up the river. It has been seen that Admiral Watson started up at the beginning of the spring tides and down early in the springs, apparently so that in the event of grounding, there would be every possibility of the vessels floating on the succeeding tides which would be higher. *Kent and Tyger the largest ships to come up the river in 1757*

28. The obstructions must have been serious, as the French at Chandernagore considered themselves immune to attack, so that, according to Ives, it was "to the great mortification as well as the astonishment of the French (who had flattered themselves it would be impracticable for us to bring up our largest ships) on the 18th the *Kent*, *Tyger* and *Salisbury* appeared in sight of the fort and then turning the point of Chandernagore reach, anchored the 19th, off the Prussian Octagon, from whence we had a full view of the town and fortification......Just below the Fort of Chandernagore there was a large bank of sand which made the passage very narrow; to block up this channel, they had sunk three ships loaded with ballast, the masts of which, however, appeared above water." Ives' Journal

29. The vessels crossed Barrackpur bar on the way up with a rise of tide of about 8 feet and on the way down the *Kent* warped across with 10 feet 6 inches rise. Now even assuming the vessels were of 19 feet draft, the depth over the bar reduced to present datum must, therefore, have been something greater than 12 feet and yet less than 18 feet, otherwise it would not have been generally recognised as a shoal in those days. Considering the evident difficulty of crossing the bar and the pains taken to cross at high-water, it may be accepted with a fair degree of accuracy that the depth was between 14 and 15 feet, which would have given 22 to 23 feet at high-water **Conclusions as to approximate depth on Barrackpur and Ichhapur bars in 1757**

on the 17th March when the ships passed upward bound and 24 feet 6 inches to 25 feet 6 inches depth at high-water on the 5th April when the *Kent* passed down. On the Ichhapur bar, which the vessels crossed at high-waters of 9 feet and 9 feet 6 inches, the reduced depth must have been approximately the same as on the Barrackpur bar, or about 14 to 15 feet. The depth on those two bars in 1757 may therefore, have been one to two feet, and certainly not more than 2 feet, greater than it was in 1909, when the depth on both bars was 13 feet. As the *Kent* had to work across the 'Barnagull' shoal on the 6th April 1757, a bar of from 16 to 18 feet must have existed in that locality where there is now nothing less than 22 feet of water, though there is a 19 feet bar higher up at Ariadeh.

30. From this comparison between the modern state of the channels above Calcutta and the conditions 160 years ago, the following conclusions may be drawn:—

Conclusions from foregoing comparison of state of Upper reaches of Hooghly

The bar at Bansberia is of approximately the same depth now as formerly. The shoal at Chinsura has deteriorated from 10 or 12 feet to 3 feet, but this is probably only due to local causes and cannot be taken to indicate general deterioration. The bars at Ichhapur and Barrackpur may have deteriorated, but very slightly, while the channel lower down at Barnagur has improved. As a matter of fact the conditions in the Upper section of the Hooghly cannot be said to have altered materially in the past 160 years, though in 1757 the Kunti Nadi branch of the Damodar was probably active.

Comparisons of surveys of 1884-85 and 1909

31 In recent times, two surveys have been made, one in 1884-85, in which the soundings of the river were taken up to Shamnagar, and another 24 years subsequently in 1909, when the river was completely surveyed as far as Bansberia. A section of about 11 miles from the northern boundary of the Port at Cossipur to the narrowest point above Barrackpur has been taken and corresponding cross sections in it, at intervals of 1,000 feet, have plotted and the areas calculated. These have been shown as curves (Plate No. 14), the area in square feet being represented vertically and the distance in lineal feet along the axis of the river horizontally, and from the figures, the cubical contents of the river at high-water (18 feet) and at datum (lowest low-water) have been calculated with the following results.—

Year	Cubical contents at low-water (datum)	Cubical contents at high-water, 18 feet rise
1885	1,900,170,000 c. ft.	4,365,720,000 c. ft.
1909	1,903,430,000 „	4,372,770,000 „

It will be seen that the change is practically inappreciable, being slightly greater in the latter year The surveys were unfortunately made at different seasons, that in 1885 being at the end of an abnormally high freshets in November, while in 1909, the soundings were taken near the end of the flood-tide seasons after an ordinary freshet, so the advantage in this respect was in favour of the earlier year

Variation of cross sectional area with change of tidal conditions

32 An examination of the curves will show how considerably individual cross sections vary in the course of even three or four months in the dry season; this, of course, is to be expected with the changing tidal conditions, as the cross sections most favourably situated with regard to the flood and ebb currents, naturally oscillate in area as the one or the other tide predominates, so that one part of the river fills, while another part scours alternately in different seasons. It is evident under these conditions that it would be hopeless to endeavour to ascertain whether general conditions had changed by a comparison of individual and isolated cross sections and it was in order to eliminate the effects of these fluctuations in sectional areas due to seasonal variations, that the foregoing method of comparing capacities of a strip of river by taking sectional areas a short distance apart and deducing therefrom the cubical contents, has been adopted. In this connection, it may be remarked that it would be very unsafe to draw general conclusions, such as those deduced by Major Hirst regarding the rise of the river bed with a fall in water-level, simply from a comparison of a single section taken below the Jubilee Bridge in different years (pages 37 and 38 of his Report). The section was in each case taken in a different month, from 5th February to 5th June, and as already explained varying tidal conditions might cause considerable variations in area at different times in the same year and, moreover, the proximity of such a disturbing factor as the bridge would of itself vitiate any conclusions from the results. Major Hirst further states that the circumstances when the section of 1883 was taken were abnormal as a bund had been constructed across the Bhagirathi entrance which did not burst till the 18th June, thus preventing the usual rise of the Bhagirathi due to the rise of the Ganges in April.

Futility of comparison of individual and isolated cross sections

33. The spill from the Ganges through the Bhagirathi is seldom appreciable before the middle of June and in 1900 and 1901 two of the years under comparison, the level at the entrance did not being to rise till the beginning of June, and then rose only 2 feet by the 18th of the month, so that the effect on the Hooghly would have been inappreciable. From the gauge records at Berhampur the levels in 1885, both before and after the bursting of the embankment, were not exceptional, and the conditions in that year cannot be said to have been abnormal even in the Bhagirathi and consequently they would have been even less so on the Hooghly.

Effect of Jubilee Bridge

34. Owing to the deposit of large quantities of stone, the erection of the Jubilee Bridge has probably had certain local deteriorative consequences which have affected the channel lower down at the site of the Chinsura are, but what is of far greater importance is its effect on the general regimen of the river. Its influence may possibly be traced in the sharp rise of the low-water line between Gauripur and Dumardaha, which will be dealt with in the consideration of the Hooghly tides.

35. To return to the comparison of the surveys of the upper portion of the river, longitudinal sections have been plotted from surveys made in 1875 to Barrackpur and in 1885 and 1909 to Shamnagar, reproduced on Plate No. 19. It will be remarked that the 1875 section is the worst of the three and more water was available over the chief bars at Barrackpur and Ichhapur in 1909 than in 1885. The foregoing comparisons of the cubical capacities and longitudinal sections, indicate that at least there had been no progressive deterioration of the upper section of the Hooghly between 1875 and 1909 and probably an improvement. Reclamation works and encroachment on the channels have, however, been in progress, and the effects of some of these works will probably be deleterious and will now begin to be increasingly manifest.

Comparison of longitudinal sections of Upper section of Hooghly.

Conclusions

Effect of works of reclamation

36. Since 1885 there have been considerable changes opposite Chinsura, but these have been largely due to the effect of the Jubilee Bridge. Owing to accretion on the left bank below the bridge, the Gouripur Mills have been compelled to extend their jetties considerably and have consolidated a great portion of the inner ends. Now, as pointed out before, about this site the river changes its character from an unstable to a fixed regimen and it is possible that the movement of the channel close to the right bank was due as much to alteration in the river above, as to the effect of the bridge. The change may, therefore, very probably have been a natural oscillation, so that in course of time, the channel might tend to travel across again and this movement will be restricted by the works since carried out on the opposite bank. A large island, or in fact two islands, which existed opposite and below Chinsura College in 1884 remained in position, though probably diminishing in size till after 1896. They have since entirely disappeared and the channel has, therefore, been considerably widened and has consequently shallowed.

Changes at Chinsura between 1885 and 1909

37 These changes have taken place where the river has not fully established a fixed regimen and are consequently not now of the same significance as considerable erosion or accretion lower down, but with the fixation of the banks owing to the erection of mills above and below the bridge, the regimen of the river here will be more stable in the future. Between Chinsura and Cossipur the natural tendency is for erosion to take place along the bights As the banks are hard and fairly well consolidated, the rate of erosion is generally very small, being about 2 to 3 feet a year and slightly greater opposite Barrackpur and the Park where the high-water line has cut away about 100 feet since 1885 However, in places such as at the Palta Waterworks, pockets are eaten out, owing to eddy action in softer soil and the erosion in such places is very much greater Natural accretion is almost entirely absent, but at one place opposite Palta Point, the right bank has since 1885, filled in about 400 feet below a sharp point This has obliterated the point and made the bank regular. This accretion may have been natural, but the point which is shown on the 1885 chart appears very unnatural and the indications are that it had then been recently built out artificially for brick-making purposes

Natural changes between Chinsura and Cossipur

Only one case of natural accretion

38. Cases of artificial reclamation are very frequent in this section of the river. Below Chinsura, the left bank from the Anglo-India Jute Mill has been built out, till the point opposite Chandernagore had in 1909 been thrust out as much as 250 feet beyond the high line of 1885 and the jetties of the Alliance and Alexandra Jute Mills jut out over 200 feet further into the river This is at a place where the river is already very narrow, being now only 1,400 feet wide and the reclamation which continues down to the Auckland Jute Mills, accentuates the bend. The effect on the opposite side is shown by a cutting away of the right bank to the extent of 200 feet about midway between Chinsura and Chandernagore, but below this and right opposite the point, a new mill has been erected. This has consolidated the bank along *chur* land which the river formerly overflowed and has further restricted the channel.

Cases of artificial accretion

Reclamation at Kankinara

39. At Paikpara, the first point below Chandernagore, the Victoria Jute Mills have built up and consolidated low ground opposite the sharp bend at Shamnagar. From Champdany Point to Baidyabati, the right bank has been raised and consolidated for brick fields, but for the most part, the river here is wide At the lower end, where it narrows at Palta Point, the accretion mentioned before has caused restriction Below Serampur, from the Howrah Water-works at the point, to the Wellington Jute Mill, there has been considerable reclamation for an average width of 300 feet in a mile of foreshore. The accretion at the point at Mahesh opposite Kharda had been as much as 400 feet between 1885 and 1909 and the river here is now just over 1,500 feet wide the Wellington Jute Mill jetty here has been extended about 150 feet. The cause of this reclamation can only be attributed to the spur and jetty built out by the Bengal Luxmi Cotton Mill which appears to have affected the bank above and below it, and this also appears to have caused deterioration in the river channel below Kharda, as a patch of shallow water giving 16 feet depth appears in the 1909 chart in mid channel where the channel was clear with nothing less than 24 feet in 1885. Below Kutrang Point, there has been considerable reclamation for brick-fields and this has carried the high line in the middle out as much as 500 feet.

Victoria Jute Mills at Paikpara

Accretion from Champdany to Baidyabati

Great reclamation at Mahesh

Effect of spur and jetty of Bengal Luxmi Cotton Mill

Brick-fields at Kutrang

40. The greatest reclamation has, however, taken place at Calcutta itself. The right bank from the northern boundary pillar of the Port to Salkia, is being gradually thrown out and reclamation has proceeded extensively in the past 20 years along the Howrah foreshore down to Shalimar Point, where the former timber ponds have been filled in and the land raised to above high-water level. From Shalimar Point to the Botanical Garden, spurs have been thrown out to enclose new timber ponds, and the enclosures have silted up largely. On the left bank below Ahiritollah Ghat, the foreshore has been extended generally and quite recently large reclamations have taken place just above the Howrah Bridge for the new inland vessels' wharves and warehouses. The jetties have been built below the bridge and recently extended to Chandpal Ghat. Below Fort Point,

Reclamation in Calcutta

a large strip of land has been reclaimed leaving Prinsep's Ghat which in 1875 was on the river bank 280 feet inshore.

Comparison of chart of 1793 and 1918

41. The extent to which the artificial reclamations have encroached on the river in the Port is shown approximately on map No. 17 where the present conditions are contrasted with those in 1793. It will be observed that what was a concave bank from Ahiritollah Ghat to Chandpal Ghat has been now carried out to practically a straight line for purposes of wharves and jetties. The river at that time extended well back to beyond the line of the present Strand Road and the maximum reclamation has taken place at about the present position of the Mint. A great deal of this reclamation is quite recent and has reduced the throat of the river at its narrowest part at the Howrah Bridge. On the right bank, land has been reclaimed on the Howrah side to about half the width of the river in 1793.

Wise control required over works on river bank

Beneficial effects of erection of Jute and other mills on banks in places

Prejudicial effect of works on river banks.

Effect on tidal river different to that on non-tidal river

Reduction of tidal reservoir

42 It is recognised that the erection of mills and works on the river bank is a necessary concomitant of the industrial expansion which fosters the trade of the port, but wise and far-seeing control is needed to preserve the necessary balance between the interests of the conservancy of the river and those of local industries which are mutually interdependent. As a matter of fact, the erection of mills along the river bank is in most cases far from being prejudicial to the river. On cutting banks, walls are usually built to protect the foreshore and this fixation of the banks where natural erosion is active prevents undue widening and helps to preserve the general regimen. However, in many cases, mills are built at points or on the convex banks. Under these circumstances, the depths at the jetties are naturally shallow at the worst season and the tendency is to extend the jetties and consolidate the inner ends and low-lying land inshore. These then form natural obstructions to the flow of the flood-tide, accentuate the bends and cause accretion along the bank, where areas over which the tide spilled at high-water are reclaimed. The argument is sometimes put forward that the effect is simply to deepen the channel on the opposite side and so the river maintains its discharging capacity. This would most probably be the case in a non-tidal river where the effect of an obstruction, even if harmful, would be local, but the circumstances are quite different in a tidal river In such a river as the Hooghly which depends for eight months in the twelve on tidal action to keep the lower channels open, interference with the flow of the flood-tide reduces the force of the tide wave above the obstruction. The downward swing of the ebb tide is consequently diminished and the river bed may, therefore, fail to react to the reduced width and the restriction in cross sectional area would become permanent and the tidal reservoir reduced.

43. The resulting restriction of tidal influence in the upper reaches would have a generally harmful effect on the whole regimen of the river and consequently all works which tend to obstruct the tide-wave have to be carefully considered in their general, apart from their local effects. For instance, a bridge such as that contemplated for the East Indian and Bengal Nagpur Railways at Bally-Uttarpara may apparently provide sufficient waterway for the ordinary discharge, but the number of piers in the river bed may, by opposing the natural movement of the tide, considered as a wave and not as current, reduce tidal action above it with harmful consequences to the general regimen

CHAPTER VI.

The Tributaries of the Hooghly.

Drainage from khals on the west between Nadia and Damodar outfall

Rough estimate of discharge from western khals

Maximum rate

1. Before dealing with the Hooghly river proper as the approach to the Port of Calcutta, a description may be given the various tributaries which augment the supply from the Nadia rivers. The drainage of the Burdwan, Hooghly and Howrah districts, south of Nadia and east of the Damodar channel, is carried into the Hooghly on its right bank by various fairly large creeks or khal such as the Kharia Nadi already mentioned, the old Saraswati river or Sankrail khal, Daokoh and Chak Kasi khals above and below Budge-Budge. Uluberia creek at Uluberia, Hog river creek entering opposite Brul Point and Pukuria creek opposite Fisherman's Point. In addition, the regular drainage of the Howrah district including that from the Rajapur bil to the west of Howrah is carried through sluiced outfalls at Baidyabati, Bally, Garden Reach, Pir Serang and Sisbaria. None of these individually, carry an appreciable supply into the Hooghly and no figures are available, but calculating from the rainfall and run off, the total supply from these sources and smaller khals from the west into the Hooghly from Nadia down to the Damodar outfall, may be roughly estimated at about 2,500 million cubic yards, or an average discharge of about 4,270 cusecs during the six months from 1st June to 30th November. With a general run off of about 1 inch, the maximum rate from all these sources combined would be about 30,000 cusecs

Drainage from country east of Hooghly

2. A smaller quantity is brought by the drainage from the country to the east through creeks, such as Fulta khal and the large drainage outfalls at Akra, Budge-Budge and Royapur. The new Magra Hat Drainage scheme which drains the lower part of the country east of the Hooghly has a sluice and lock at Diamond Harbour where the former large creek has been dammed across, and there are other drainage outfalls at Kalpi and at Tengra inside the Rangafala island. All these latter, however, are only minor systems which carry the local surface water and they do not contribute materially to the Hooghly supply.

Tributaries of Hooghly

3. The tributaries proper of the Hooghly are four in number, the Damodar, Rupnarayan, Haldi and Rasulpur rivers, all entering from the west on the right bank of

the river. The Rasulpur, however, discharges practically at the sea-face and so has no influence on the navigable channels of the Hooghly.*

Damodar river
Barakar river

4. The Damodar, which has its source west of Ranchi and Hazaribagh, drains the Chhota Nagpur hills. It has one large tributary, the Barakar river, rising north of Hazaribagh. After passing the town of Burdwan, the Damodar makes a great right-angled bend above Selimabad and then flows south past Amta, the actual river channel falling into the Hooghly opposite Fulta Point at the head of the James and Mary Reach.

Damodar in 16th century according to De Barros, Kana Damodar
Van De Broucke's map, 1660
Baksi khal
Kalna branch of Damodar

5. According to De Barros, the main channel of the Damodar in the 16th century apparently followed the course of the present decayed Kana Damodar khal taking off below Selimabad and entering the Hooghly at Uluberia where there was an island. Later in the 17th century, Van Den Broucke's map, 1660, shows the main Damodar flowing south into the Rupnarayan somewhere in the position of the present Baksi khal: a smaller branch entering the Hooghly by the present Damodar channel and a large branch, already mentioned, flowing straight past Burdwan apparently along the line of the Gangur Nadi and falling into the Hooghly near Amboya or Kalna. Shortly after, this Kalna branch was deserted. The Kana Damodar channel entering the Hooghly near Uluberia apparently became the main Damodar channel and another northern branch opened. This took off also at the great bend near Selimabad following the course of the present Kana Nadi south-east to near Gopalnagar, where it made a wide sweep and turning north-east along the present Kunti Nadi entered the Hooghly at Noaserai* where the remains of the old channel are still easily discernible. This appears to have been the position towards the latter end of the 17th century. A chart of about 1690 reproduced as map No. 9 shows the Kana Damodar called the Jon Perdo river, as quite a large stream entering the Hooghly near Uluberia where the formation of a large island shows that the tributary must have been of some magnitude.† An insignificant creek no bigger than the ordinary khals and called the Mandala Ghat river marks the present position of the entrance of Damodar opposite Fulta Point The Kana Damodar seems to have decayed rapidly, probably owing to a diversion of its supply into the Kana Nadi and in a revised edition of the 1690 chart, emanating probably between 1720 and 1730, the Jon Perdo river is shown much narrower and the island in the Hooghly had disappeared. Later in a map of about 1760, the Jon Perdo river had deteriorated into a creek called the Goreeganga probably intended for Buri Ganga or old Ganges. The influence of a large tributary entering on the opposite side of the river previously, is shown on this map by the unnatural concavity of the left bank of the Hooghly above Uluberia. The bank adjusted itself gradually to its present or normal condition, but in Ritchie and Lacam's chart of 1785, the concavity is still well defined though the Kana Damodar is represented as an insignificant creek. In the meanwhile, changes had been taking place in the upper branch of the Damodar, or Kana and Kunti Nadis. This in its latter portion had an obviously unnatural direction to the north-east which will be realised by the fact that the Saraswati river, which left the Hooghly at Tribeni about three miles below Noaserai, would have been flowing in a generally parallel but reverse direction to the Kunti Nadi, at times only a mile away from it. The latter must, therefore, when the Hooghly level was high, have acted as an effluent owing to the Hooghly water backing up into it and only been changed to an affluent when the periodic floods came down the Damodar The inhabitants of the adjacent country probably endeavoured to maintain the channel of the Kunti Nadi by the construction of marginal embankments and this stream may have been given in this manner an artificial and precarious existence for a period It probably took an increasing supply diverted from the Kana Damodar, and the bed level under the conditions was probably rapidly raised, particularly in the Kunti Nadi, until the channel could no longer accommodate the supply. About the middle of the 18th century, the Damodar suddenly deserted this branch and took a southerly course past Amta flowing into the Hooghly by its present channel or the Mandal Ghat river.

Kana and Kunti nadis
Noaserai branch.
Chart of 1690
Jon Perdo river
Mandal Ghat river
Chart of 1720, 1730
Map No 10
Chart of 1760
Ritchie's chart, 1785
Map No 11
Unnatural conditions of Kunti Nadi
Diversion of Damodar, 1757

6. Rennell about 1760 refers to the Kana and Kunti Nadis as the old Damodar and indicates that the river deserted this channel in 1757. In a map by Du Gloss, one of Rennell's assistants, dated 1766, the lower Damodar is shown very much as at present though narrower at its mouth and called by its old name, the Mandal Ghat river. It split at Amta into three small creeks, so that the high flood discharge of the Damodar must have spilled and could not have been carried into the Hooghly by one channel. It seems probable that the Damodar has at no time discharged all its water into the Hooghly above its present outfall, but before the middle of the 18th century, at times quite a fair percentage of its supply must have entered above the Moyapur bar when the upper branches, such as the Banka Nadi, the Kunti Nadi and the Kana Damodar alternately were operating. Since the last diversion of the Damodar about 160 years ago, the Upper section of Hooghly has been deprived of this additional supply. It is a fact that the great Damodar floods at the end of September, 1823, affected the river levels at Calcutta considerably and the low-water level was raised to the extraordinary height of 20'-6" above Kidderpur Old Dock Sill, the range of tide for the day at Calcutta being only 19 inches, so that a considerable portion of the Damodar supply must have poured into the Hooghly above Calcutta. This must, however, have been for the most part cross country spill from Burdwan and flow by the Kana Nadi which was not finally closed till about 1866 and this accentuated the already high-level of the Hooghly due to the abnormal Ganges supply of that year. While the Damodar was spilling through the Kunti and Kana Damodar branches, it must have built up the weak places along the left bank until

Du Gloss' map
Whole Damodar discharge never entered Hooghly above Moyapur
Deprivation of certain amount of supply since 1757
Extraordinary low-water at Calcutta in September 1823 due to Damodar floods
Raising of left bank of Damodar and consequent diversion of Noaserai branch.

* Map No. 5.

† The present Chak Kasi Khal is probably the remains of this branch of the Damodar Refer also to map No. 9

the channel was diverted into the Amta route. The tendency would then have been for the channel to travel westward and we know that in the middle of the 19th century, considerable damage was done, due to floods pouring over the right embankments which in 1851 were in a very bad state of repair. It was decided to remove these embankments altogether for twenty miles from Sangatgola, twelve miles above Burdwan, right round the great bend of the river and this was completed between 1856 and 1859. In 1865 the great Begua breach at the lower end of the abandoned right embankment opened and since then practically all the heavy spill from high floods has poured over the right bank of the river and through the country to the west of the Damodar into the head of the Rupnarayan between Bunder and Ranichak. The removal of the right embankments relieved the pressure on the left bank of the river, but the result of the unrestricted spill on that side since the middle of the 19th century has been such, that the right margin of the river has been raised, until in places it is now as much as 9 feet higher than the adjacent country to the east of the river. The river bed has also been rising and the consequence is that a severe strain is now thrown on the left embankment during heavy floods. The tendency is now for the river to force a passage again through Burdwan into the Hooghly near Kalna and the consequences of this avulsion would be so serious, not only as regards the damage to the intervening country and the town of Burdwan, but also in its effect on the Hooghly, that remedial measures are being earnestly considered. The most satisfactory solution appears to be the construction of reservoirs in the Barakar valley to impound the supply, so as to regulate the discharge during abnormal periods of rainfall.

Floods over right embankments in middle of 19th century. Removal of right embankment. Opening of Begua breach, 1865. Heavy flood of Damodar passes into Rupnarayan. Raising of right bank of Damodar. Tendency for Damodar now to flow into Hooghly at Kalna. Remedial measures. Reservoirs in Barakar valley.

7. The foregoing probable history of the Damodar has been sketched in some detail, as in the past its influence on the development of the Hooghly channels has undoubtedly been considerable and it may conceivably again play an active part in the future It will have been seen that the river is an active delta builder. It has a drainage basin of 7,211 square miles above Raniganj, where it carries a maximum discharge of as much as 650,000 cusecs, as in August 1913. The discharge is carried down from the hilly country in sudden torrential rushes, the floods rising and subsiding rapidly, the duration of the flood varies ordinarily from one to three days, though in August 1913, it lasted for 123 hours Great quantities of sand are carried down in these tumultuous rushes, which are deposited when the current enters the flat country below Raniganj. The river is consequently unable to scour out and maintain a single adequate channel and the flood spills over the country. Any main branch of the river which carries the ordinary discharge is gradually built up on a ridge by the raising of its bed and banks by spill, until the conditions become impossible and the river deserts this channel for a new one through the low-lying adjacent country. The construction of reservoirs while reducing abnormal flood heights would regulate the discharge and prolong the duration of the floods, so giving the river channel a better chance of carrying the suspended sediment and the present main or Amta channel may under these circumstances be expected to improve.

Drainage basin of Damodar. Maximum discharge. Incidence and duration of floods. Deposit of sand forming cone area at head of delta below Raniganj. Raising of bed-level of main branch. Beneficial influence on river channel of regulation of discharge by reservoirs.

8. The average monthly discharges with minimum and maximum rates of the Damodar for the rainy season from 15th June to 15th October, are given in the statement at the end of this chapter these have been calculated from the gauge heights at Raniganj for the period 1913-17. It will be seen that the maximum discharge in 1916 and 1917 reached to nearly 400,000 cusecs, while in August 1913, it was 650,000 cusecs with a gauge height of 22 feet 11 inches, these rates are, however, only maintained for a few hours. However, the total quantity discharged in the August flood of 1913 was as much as 5,053 million cubic yards in 123 hours and this was over 27 per cent of the total discharge for the whole four months of that season and over 50 per cent. of the total discharges for the rainy seasons of 1914 and 1915. From the statement it will also be seen that with a temporary cessation of rain, even during the monsoon months, the discharge of the Damodar sinks to practically nothing

Average monthly discharges and mean, minimum and maximum rates. Total quantity of August 1913 flood discharge.

9. The total quantities discharged by the Damodar in the four months of the rainy season from 15th June to 15th October are given in the statement as varying between 8,517 million cubic yards in 1915 and 26,568 million cubic yards in 1917, in which year there were four distinct floods. With the exception of the loss due to evaporation and absorption *en route*, practically the whole discharge of the Damodar at Raniganj eventually reaches the Hooghly, but with regard to the effect on the channels of the latter, it is of importance to know the proportions of the supply carried by the different channels into the parent stream. In the 1913 flood, of the 650,000 cusecs discharging at Raniganj, 158,000 cusecs passed through breaches in the left embankment through the town of Burdwan and into the Hooghly by the Banka Nadi and over the country west of Kalna, and another 16,000 cusecs went through breaches in the left embankment lower down and entered the Hooghly near Uluberia The rate of discharge by the time all this water reached the Hooghly was naturally very much reduced, and it had no effect in raising the river levels at Calcutta. Four hundred thousand cusecs spilled over the right bank above and below Burdwan and found its way into the Baksi basin of the Rupnarayan. The remainder, 50,000 cusecs, passed through the Amta channel. After the flood had passed down the river, probably another 50,000 cusecs spilled back in the vicinity of the Ghaighata khal from the Baksi basin, thus prolonging the discharge into the Hooghly at Fulta Point. When bank full, the Amta channel is calculated to be able to carry not more than 50,000 cusecs and last year, 1917, the dry season discharge of the Damodar passed through this channel, so subtracting all discharges over 50,000 cusecs and taking two-fifths of the balance, allowing three-fifths for spill in the low-water periods through the Begua and other channels on the right bank, we may arrive at a rough guess of the total discharge

Variations of total seasonal discharge of Damodar in recent years. Proportions of spill of Damodar. Maximum rate of discharge of Damodar into Hooghly at Fulta Point. Total discharge into Hooghly at Fulta Point.

for the season through the Damodar channel at Fulta Point. This gives a total amount of 6,000 million cubic yards, or an average rate of discharge for the four months of 15,000 cusecs. This was, however, in a year of abnormally high discharge; on the other hand, in such a year as 1915, when the Damodar discharge was abnormally low and taking two-fifths of this discharge below 50,000 cusecs, the total quantity passing through the Amta channel into the Hooghly, would be about 2,600 million cubic yards, or at an average rate of 6,600 cusecs for the four months.

10. The average total discharge of the Damodar from 15th June to 15th October for the period from 1913 to 1917 was approximately 16,000 million cubic yards, and this would be probably about the average annual discharge of the river. Of this quantity roughly an average of 6,800 cusecs for the six months from 1st June to 30th November, or a total quantity of about 4,000 million cubic yards reaches the Hooghly at Fulta Point and the remainder by the Rupnarayan.

Average total annual discharge of Damodar

Proportions entering Hooghly at Fulta Point and at Hooghly Point

11. The Rupnarayan is formed at Bunder, just east of Ghatal, by the confluence of the Dalkhisor and Selai rivers, both rising east of Purulia (Manbhum) After passing Tamluk, it expands into a wide basin and then enters the Hooghly through a narrow but deep neck at Gewankhali opposite Hooghly Point and at the lower end of the James and Mary Reach. About 15 miles above Tamluk, the Rupnarayan is crossed by the Bengal-Nagpur Railway at Kola Ghat and 10 miles further up, the Baksi khal takes off from the left bank and connects the Rupnarayan with the Damodar through the Ghaighata khal. The Selai river has a catchment area of 1,384 square miles with an estimated flood discharge at Garbeta in its upper reaches, of 72,063 cusecs, while at Ghatal near its confluence with the Dalkhisor, the flood discharging capacity is only about 21,566 cusecs, the remainder spilling over the country to the north The Dalkhisor basin is of somewhat the same extent as the Selai. There are no data regarding the total discharges of these rivers, and as it is necessary to arrive at some idea of the supply brought by them into the Hooghly, I take a run off of 60 per cent. for a year of average rainfall of 50 inches for the whole basin of about 2,800 square miles and get a total quantity of 7,000 million cubic yards

Rupnarayan river

Baksi khal

Ghaighata khal

Selai river flood discharges

Dalkhisor river

Total average supply from Selai and Dalkhisor

12. The Kosai river which rises west of Purulia and flows past Midnapur, spills during high-flood over its left bank below that town and this spill together with the discharge through a branch of the river at Kapastekri, finds its way into the Selai at Dewan Chak south-west of Ghatal It has been calculated that of a total flood discharge of the Kosai of 187,000 cusecs at Midnapur, about 142,000 cusecs spilled over the left bank into the Selai, and with a moderate flood of 110,600 cusecs at Midnapore, 60,000 cusecs spilled above Kapastekri. Owing to the restricted channels of the Kosai and Dalkhisor at Ghatal and Bunder, the surrounding region is subject to severe inundation during heavy floods, which is accentuated by the backing up of the discharges of these rivers when there is a heavy flood spill from the Damodar into the head of the Rupnarayan The lower channels of that river are incapable of passing the whole discharge and the combined spill is then held up in the country above the Baksi khal which forms a reservoir or basin. The spill is passed at a regulated rate through the narrow neck of the river below the Baksi khal and it is estimated that at the Kola Ghat bridge, the maximum discharging rate of the Rupnarayan is 235,000 cusecs; this would probably be the approximate maximum rate of discharge into the Hooghly at Gewankhali The approximate total average discharge of the Damodar into the Rupnarayan has been estimated at 12,000 million cubic yards, adding to this 7,000 million cubic yards as the average supply from the Dalkhisor and Selai rivers and, say, 4,000 million cubic yards spill from the Kosai, the total discharge which enters the Hooghly in an average year through the Rupnarayan channel would be 23,000 million cubic yards giving an average rate for the six months from 1st June to 30th November of about 39,300 cusecs In an abnormal year such as 1917, when about 21,000 million cubic yards overflowed into the Rupnarayan from the Damodar, the total supply discharged into the Hooghly would have reached about 35,000 million cubic yards at an average rate of about 60,000 cusecs during the period from 1st June to 30th November.

Kosai river Flood spill into Selai

Inundated area at Ghatal

Baksi basin or reservoir

Maximum discharging rate of Rupnarayan into Hooghly

Total average discharge from Rupnarayan and average rate

Abnormal total discharge in 1917

13. In addition to this fresh water-supply, the Rupnarayan provides a magnificent basin or reservoir for the reception of tidal water and the influence of this river on the Hooghly is shown in the splendid wide and deep channel scoured from the confluence, right down to Kalpi, a distance of nearly 15 miles, by the combined discharges of the two rivers. As in the case of the Rasulpur and Haldi and many other rivers, tidal spill in the upper portion of the Rupnarayan has been completely restricted by the construction of embankments, shutting out tidal water. This action has ruined rivers, such, as the Rasulpur and others in the Sundarbans.

Tidal basin of Rupnarayan

Restriction of tidal spill

14. In the basin of the Rupnarayan above the neck at Gewankhali, great changes are continually taking place. The area is largely occupied by low islands, or churs, which are more or less completely covered at high-tide, and these churs are continually changing form. A few years ago, erosion was extremely active on the right bank just above the neck and threatened to cut into the Orissa canal some miles away from the Gewankhali lock. This erosion suddenly ceased, and in a couple of years or so, the whole bight which had been scooped out, refilled and became chur land. Erosion was again taking place actively along the right bank higher up last year and in a survey which was being made, the coast line had to be mapped and soundings adjacent taken almost simultaneously and the whole work had to be completed in a fortnight, otherwise the parts of the chart would have been changed in relation to each other.

Basin of Rupnarayan below Tamluk

Active erosion of right bank of Rupnarayan

Haldi river Kaliaghai river.

15. The Haldi river is formed by the confluence of the Kaliaghai river, rising south-west of Midnapur, with the lower branch of the Kosai river. It enters the Hooghly through a fairly wide estuary at Sandia opposite Mud Point. There are no data as regards the discharge carried into the Hooghly. As we have already stated, during floods the greater portion of the Kosai discharge spilled into the Selai river, the maximum quantity coming down the Kosai channel being about 30,000 cusecs. Taking a maximum run off of 2, inches for the 550 square miles of catchment of the Kaliaghai river and allowing a percentage for spill, the maximum rate of discharge of this stream would be about 20,000 cusecs. The maximum rate of fresh water discharge of the Haldi with the Kosai and Kaliaghai rivers in full flood would, therefore, be about 50,000 cusecs, and during the dry season the discharge is practically nil. The total average discharge for the year, of the Kosai with a basin of 2,900 square miles, may be estimated at about 7,400 million cubic yards, giving a run off of 60 per cent. Of this perhaps 4,000 million cubic yards finds its way into the Selai and the remainder which comes into the Haldi, would be 3,400 million cubic yards. Estimating in the same way, the total discharge from the Kaliaghai catchment would be approximately 1,500 million cubic yards. The total annual fresh water discharge of the Haldi into the Hooghly would, therefore, be 4,900, say, 5,000, million cubic yards. The Haldi estuary provides a tidal basin, the influence of which on the Lower Hooghly is shown in the maintenance of the deep water anchorage of the Jellingham channel below the confluence and off Mud Point This tidal reservoir has been restricted gradually by the construction of bunds shutting out tidal spill from low-lying lands along the river bank with the result that the Haldi has deteriorated.

Maximum spill of Kosai into Haldi.

Maximum rate of spill of Kaliaghai into Haldi

Total average discharge of Kosai.

Proportion entering Haldi

Total discharge of Kaliaghai

Total discharge of Haldi into Hooghly

Rasulpur river, a dead river

16. The last tributary of the Hooghly is the Rasulpur river entering on the right bank at Hijili This river has now practically no influence on the channels, though formerly it helped to maintain the western channel approach to the Hooghly. It is referred to here simple as a classic example of the evils of interfering with tidal spill. The river had deteriorated very considerably between 1885 and 1895, and it has now degenerated into a large khal which it is proposed to dam across, providing a sluiced outfall for the natural discharge, thus completely shutting out all tidal water. The commencement of the process of degeneration is depicted in Mr Apjohn's lecture at the Sibpur Engineering College on "Silt in the rivers of Bengal" already mentioned. "In the case of the Rasulpur river the enormous increase in the proportion of silt found in its water by me, compared to that determined by Mr. Vertannes ten years earlier, is not to be explained by the different season of the year at which the experiments were made, but by the fact that the river had in that period much altered in character. Formerly it used to be of great depth at the place where the canal locks into it, so deep, indeed, that none of the old sections which cross it recorded in the Executive Engineer's office, show the depth, but in consequence of the reclamation of low-lying jungle land along its banks which used formerly to be flooded by high tides, having reduced the tidal scour, the river rapidly silted up, until in 1885 it had become almost fordable at low-water, where formerly it had been so deep, and since then it has become fordable. The very strong tides of May rushing over the mud flats now formed, naturally stirs up the deposit until the water becomes practically liquid mud You see that on the 15th May 1885, the water actually contained 5 per cent of solid matter The Haldi is another river which has changed its character for the worse for the same cause, though not to the same extent as the Rasulpur. I found four times greater a proportion of silt in its water than Mr Vertannes had done ten years earlier, but in that the of Rasulpur fifty times. Twenty years ago the Rasulpur carried the less silt of the two and the second range of the Hijili tidal canal which was first constructed to be filled from the Hadi was altered in 1876, so as to receive its water from the Rasulpur, but of late the former source of supply has been reverted to. Compared with the Rasulpur and Haldi, the other rivers whose waters have been experimented on are clear and limpid streams."

Deterioration of river due to interference with tidal spill.

Mr Apjohn's description of increase in silt charge of Rasulpur

17. Mr. Apjohn's remarks will be borne out by anyone who has had experience of the flats at the mouth and north bank of the Rasulpur which are of hardly greater consistency than slime; any current running over these flats stirs up the mud and the sediment which is carried up the river with the rush of spring flood tides is very great. As the spill at high-water has been shut out, there is no reinforcement of the downward swing of the current and deposit takes place during the dry season, which the discharge during the rains is unable to scour completely away again A Committee appointed in 1889 to report on floods in the Midnapur district drew particular attention to this matter and attributed as one of the causes of the floods, the embankment of salt water marshes or low-lying wastes which led to the silting up of tidal creeks. They pointed out that as the creeks discharge little or no fresh water for seven or eight months in the year, the construction of embankments by interfering with the free tidal flow had caused a deposit of silt and deterioration of the creeks, so that their beds had been raised above the level of the country they formerly partially drained, with the consequence that the drainage of inland tracts in the rainy months was blocked.

Committee of 1889 on floods in Midnapur district

Opinion that deterioration of tidal creeks is due to restriction of tidal spill

18. There is practically no data as regards the silt carried in suspension by these tributaries of the Hooghly. For the Damodar in flood, Captain Garnault about 1830 gave a proportion of 1 to 590 parts of silt by volume, but Mr. D. B. Horn in 1901 gave the mean proportion as 1 in 1,200. Mr. Vertannes in 1875 determined a proportion of 1 to 2,650 for the water of the Rupnarayan. The reduction in the silt charge of the Rupnarayan as compared with Damodar is quite intelligible owing to the filtering of the spill of the latter river before it reaches the Ruynarayan by deposit on the country over which it passes.

Silt charges in Damodar, Rupnarayan and Haldi rivers.

Total average quantities of silt carried

19. In the Haldi, Mr. Vertannes got a proportion by volume of 1 in 977, or say, 1 in 1,000. Taking these figures, the total average quantities of silt carried down by the tributaries each season would be as follows :—

Damodar, 3·3 million cubic yards ;
Rupnarayan, 8·7 million cubic yards ;
Haldi, 5 million cubic yards ;

or a total of 17 million cubic yards from all the tributaries in an average year.

20. A summary of discharges of the tributaries of the Hooghly is appended. The discharges for the Damodar from 1913 to 1917 are calculated from a table compiled by Mr. Addams-Williams for the rates of discharge according to gauge levels at Raniganj, but the total, spilling into the Rupnarayan and through the Damodar channel are only roughly estimated. As data are not available and it is necessary to get some idea of the discharging capacities, the rates and totals for the other rivers are more or less roughly computed, and particularly in the cases of the Kosai and Haldi rivers are open to correction, but the discharges being small and variations in different season considerable, the error will not be appreciable in the grand total. The Rasulpur has not been taken into consideration as the discharge is small and has no influence on the Hooghly's navigable channels. Summary of discharges arrived at roughly owing to absence of definite data.

DAMODAR RIVER DISCHARGES AT RANIGANJ.

MONTHS	1913	1914	1915	1916.	1917
15th to 30th June—					
Mean rate of discharge in cusecs	35,720	14,056	18,180	26,322	44,836
Maximum rate in cusecs ...	108,800	116,500	79,700	108,800	154,500
Minimum " " ...	1,000	600	500	700	12,500
Total discharge in millions of cubic yards	1,829	7,197	930 9	1,859 7	2,296
July—					
Mean rate in cusecs ...	44,007	31,390	25,630	22,790	46,648
Maximum rate " ...	108,800	194,700	122,300	75,000	226,900
Minimum " " ...	3,000	2,000	2,000	2,000	10,100
Total discharge ...	43,654	31,138	2,540 4	2,260 8	4,627
August—					
Mean rate in cusecs ...	79,320	41,510	18,740	42,337	86,458
Maximum rate " ...	650,000	208,600	70,200	143,500	281,300
Minimum " " ...	15,800	6,800	2,000	2,000	18,300
Total discharge ...	7,868·5	4,117 8	1,859	4,200	8,576·6
September—					
Mean rate in cusecs ..	35,705	19,225	31,473	47,537	56,985
Maximum rate " ...	183,500	217,000	141,200	393,000	152,300
Minimum " " ...	3,000	2,000	2,000	7,000	17,500
Total discharge ...	3,427·7	1,845 6	3,021·4	4,563·5	5,470·5
1-15th October—					
Mean rate in cusecs ...	19,093	620	3,447	66,977	116,637
Maximum rate " ...	65,500	1,700	20,800	209,300	381,000
Minimum " " ...	2,000	2,000	2,000	19,200	35,200
Total discharge ...	916·5	29·8	165·4	3,214·9	5,598·5
Total discharge from 15th June to 15th October in millions of cubic yards.	18,407	9,826·6	8,517·2	16,099	26,568·5
Mean rate from 15th June to 15th October in cusecs.	46,764	24,966	21,644	40,900	67,506

SUMMARY OF DISCHARGES OF TRIBUTARIES OF HOOGHLY.

	Maximum discharge	Mean discharge 1st June to 30th November.
Drainage from west between Nadia and Fulta ...	30,000 (?) cusecs ...	4,270 (?) cusecs.
Damodar—		
At Raniganj	650,000 „	27,330 „
At Amta	50,000 „	
Into Hooghly	50,000 „	6,800 „
Into Rupnarayan ...	400,000 „	20,500 „
Dalkhisor into Ghatal area ...	40,000 (?) „	
Selai—		
At Garbeta	72,063 „	12,000 „
Into Ghatal area ...	121,327 „	(Dalkhisor and Selai and other khals.)
Other khals into Ghatal area ...	93,000 „	
Rupnarayan—		
At Bunder	56 000 „	
Into Baksi Basin ...	456,000 „	
At Kolá Ghat and into Hooghly	235,000 „	39,300 cusecs.
Kosai—		
At Midnapur	187,000 „	12,640 „
Into Selai	142,000 „	6,830 „
Into Haldi	30,000 „	5,800 „
Kaliaghai into Haldi ...	20,000 (?) „	2,730 „
Haldi into Hooghly ...	50,000 (?) „	8,540 „
Total into Hooghly ...	365,000 „	58,900 „

	Maximum total discharge		Mean total discharge	
Drainage between Nadia and Fulta	3,500	million cubic. yards.	2,500	million cubic yards.
Damodar—				
Into Rupnarayan ...	21,000	ditto	12,000	ditto.
Into Hooghly	6,000	ditto	4,000	ditto.
Dalkhisor into Rupnarayan Selai and Kosai spill into Rupnarayan	15,500	ditto	11,000	ditto.
Rupnarayan into Hooghly ...	36,500	ditto	23,000	ditto.
Kosai—				
Into Selai	6,000	ditto	4,000	ditto.
Into Haldi	4,000	ditto	3,400	ditto.
Haldi into Hooghly ...	5,900	ditto	500	ditto.
Total discharge into Hooghly ...			34,500	million cubic yards.

	Silt carried in an average year	
Damodar into Hooghly	3·3	million cubic yards.
Rupnarayan into Hooghly	8·7	ditto.
Haldi into Hooghly	5·0	ditto.
Total into Hooghly ...	17 0	ditto.

CHAPTER VII.

The Hooghly from Calcutta to the Sea.

Physical Characteristics and influence of tides and freshets.

1. The Lower Hooghly between Chinsura and Kantabaria comes under the influence of strong tidal forces; the banks are formed of hard material and the river has therefore a fixed regimen maintaining practically permanent channels, the variations of which in places are oscillatory in accordance with the seasonal predominance of the opposing tidal currents. The channel has been moulded by the down flowing, or ebb current and its axes ordinarily follows a succession of connected, reverse, parabolic curves with deep water clinging to the concave banks and shallowing at the crossings where the current swings from one bight to the next, leaving sand banks along the convex faces of the bends. The curves in the navigated Hooghly below Calcutta are sharpest at Sankrail and Munikhali, where the radii of reverse curvatures are only 6,000 and 6,700 feet, respectively, and as the river width is restricted at the point of cross over—Munikhali Point,—the deep water channels here merge into each other. The remaining curves have radii varying between 7,000 feet at Cossipore and 22,200 feet at Diamond Harbour.

Lower Hooghly a tidal river with fixed regimen

Channels moulded by ebb current

Curves with deep water in bends and shallower at crossings

Radii of curvatures

2. The tendency of the flood current flowing in the reverse direction to the ebb, is to create curves of contrary flexure. This influence is clearly marked in the upward extensions of the blind channels behind the sands along the convex banks, when the flood tide gains strength, but the greater hydraulic depth already created by the ebb in the bights, exercises a controlling attraction which after the first rush, draws the main axis of the flood tide into the line of the ebb and maintains the deep water channels in the bends. At the crossings where the lines again diverge, both currents lose the guiding control of the banks and individually, neither is able under ordinary conditions to carry the deep water channel across the river, though if their main axes are nearly coincident as at Kukrahati, Fisherman's Point, Kafri, Panchpara and Matiabruj crossings, a satisfactory depth is established in the channels by the combined action. Ordinarily however, where easy curves follow each other, the main axes diverge to a greater extent, but if the width at the crossing is restricted, the lead for the uncontrolled current across to the opposite bight is short and a fairly good crossing depth is maintained, as at Pujali and Pir Serang. On the other hand, if undue widening takes place at the crossing, the divergence of the main axes of the flood and ebb current naturally becomes considerable and an oval shaped intermediate neutral zone is created between them, the lead for the body of the current across the river is longer, permitting it to fan out and the loss of concentration together with the adverse influence of the reverse tide, results in a bar being formed as at Moyapur and Royapur. Under natural conditions the thread of the channel, or the line of deepest water, oscillates between the upper and lower limits of the crossing according to the season, as the flood or ebb tide predominates.

Action of flood tide current

Action of currents in crossings

Kukrahati, Fisherman's Point, Kafri, Panchpara and Matiabruj crossings afford good depth

Pujali and Pir Serang crossings

Effect of undue widening at crossing

Moyapur and Royapur bars

3. Under certain circumstances when the run of the concave bank is abruptly interrupted by a sharp bend, the axes of the flood and ebb currents may diverge until they are nearly at right angles to each other, the currents are then in direct opposition, each striving continually to undo the work of the other. This is the case at the Eastern Gut Bar of the "James and Mary," which reach, as a whole, exhibits clearly the divergent actions of the flood and ebb currents in the Western and Eastern Guts, respectively, with the neutral zone of the Makrapatti sand lying between them. The same situation occurs at Munikhali Point, but, as stated before, the lead for the uncontrolled ebb current is here so short that the deep water channels of the adjoining concaves merge into each other. However even here at the height of the dry season, the greater force of the flood tide enables it at times to push the head of the Munikhali sand into the channel at Munkhali Point, where the enfeebled ebb current cannot deal with it and a shallow crossing with on occasions as little as 23 feet depth is then formed. In the freshet season the reinforced swing of the ebb current, which swing is not naturally completed at these points, enables it again to carry the deep channel across into the deep water of the opposite concaves at both places.

Eastern Gut Bar, James and Mary Reach

Munikhali Point Crossing

Eastern Gut and Munikhali Point crossings improved in freshets

4. Shallow water also occurs in the channel at places owing to irregular alignment interfering with the even sweep of the current and causing more or less heavy eddy action, as at the Hastings shoal in Calcutta due to the protrusion of Fort Point, and the shoal which sometimes forms in the lower portion of Nurpur reach due to Nurpur Point. Ninan Bar forms in the double concave below Fulta Point owing to the conflicting action of the Damodar and Hooghly ebb currents, and the Kukrahati lumps occasionally form in the channel under the lee of Luff Point. Lastly, shallow water sometimes appears in the middle of a bight which is well sheltered from the direct action of the flood current. In these places the curl of the flood tide running up behind, tends during the dry seasons when the flood is predominant, to thrust the belly of the sand into the channel in the middle of the bight and the ebb is too weak to clear away the deposit which develops in the early part of the freshets. Shoals of 24 feet depth, and sometimes less, have frequently formed in Sankrail bight and have on rare occasions also been found at Fulta and Nurpur, but these are completely washed again during the freshet season.*

Irregular alignment induces shallowing

Hastings Bar

Ninan Bar

Kukrahati lumps.

Shallow water in bights

Nurpur and Fulta bights

---

* Only 20 feet depth was available in August 1908 in Sankrail bight and a 28 feet bar formed in Fulta bight in August 1907.

Maintenance of Hooghly channels due to interaction of flood and ebb currents
General conditions change seasonally

5. It will be seen from the foregoing description that the maintenance of the Hooghly channels depends on the more or less harmonious interplay of the ebb and flood currents, as modified by the two factors of curvature and width. The two tidal forces apart from their daily effect have an annual see-saw action. The great variation of the fresh water-supply induces a sort of bellows movement, which reaches its culmination at the height of the freshet season between the middle of August and middle of September when the "head" created by the fresh water discharge raises the mean-level of the river to its greatest height and increases its slope to a maximum. The ebb is consequently the greatly predominant current during this period, extending from about the middle of June to the middle of October when the progressive relative fall of mean river levels commences to restore the balance. Subsequently, owing to the practical elimination of the fresh water-supply and the effects of the gradual relative fall of atmospheric pressure at the head of the bay from the end of January, the flood tide increases in importance, reaching a maximum from the middle of February to the middle of April, when the actual tidal effect is greatest. The flood current at this time is more powerful than the ebb, though it does not run for the same interval of time, particularly in the upper reaches. With the increase of discharge due to occasional early rainfall and the weakening of actual tidal effect, the forces are again fairly well balanced in May and June till the downpour of freshets completely overpowers the flood tide.

Slope of river at a maximum height from middle of August to middle of September
Slope reduced to a minimum about the middle of February when the tidal effect is greatest

Channels respond to varying tidal action

6. The channels respond to the varying actions of the tides. In the freshets the heads of the sands below the points on the convex sides are washed away and the tails extend, so that the whole sand generally moves bodily downstream and the reverse action takes place naturally when the flood tides gain strength in the dry season and the heads of the sands again tend to encroach on the crossings. The longitudinal axis, or thread of the channel, fluctuates accordingly up and downstream at the crossing. The purely ebb tide channels such as the Eastern Gut, Sankrail Bight and Munikhali Crossing generally respond immediately to the increased flow and deepen with the onset of the freshets. The other normal crossings are also improved, the effect on Pujali being generally immediate, but at such places as Matiabruj, Panchpara, Pir Serang and Fisherman's Point and Fulta, the effect is at first obscured by other complications. In these places deterioration, which usually takes the form of "lumps," occurs in the earlier half of the freshets, but by the end of the season, the channels are usually scoured through, so that the upper river generally is in its best condition in November and December.

Purely ebb tide channels, Eastern Gut, Sankrail Bight and Munikhali Crossing improve with freshets, also Pujali Crossing
Matiabruj, Panchpara, Pir Serang, Fisherman's Point and Fulta deteriorate at first and improve at end of season

Freshet deterioration largely due to solid rubbish thrown into the river

7. The deterioration which takes place during the earlier half of the freshets on the crossings, is probably largely due to the following cause. Rubbish of all kinds, such as coal, bricks, clinkers, fishing stake moorings, mats, weeds, wreckage and other *débris*, has been dropped in the river in increasing quantities with the growth of traffic; this collects in the deep pools, but when the ebb current gains the necessary strength, it is started moving. The current pushes and rolls the aggregations of rubbish along the bed and up the slopes from the pools into the shallower water of the crossings, where it is thrown into the channel and tends to collect sand and silt and form lumps. These are pushed on down the channel, till at the latter end of the season they are dropped into the deeper water of the next pool, or the silt collections are washed away. The general character of these isolated lumps, standing up in deeper water, and their bodily movement, suggests that they have more or less solid cores forming centres for accretion The travel of the lumps downstream is clearly shown on the ordinary river charts of Matiabruj, Panchpara and Fisherman's Point and Fulta, as well as the Hastings Bar; at Pir Serang the aggregations form early in the freshets a bar, the regular bodily movement of which from the upper side of the crossing dowstream, till it disappears at the lower end, is a well marked feature of this crossing At Pujali, owing apparently to favourable local conditions, the ebb current does not permit the collection of deposit and the crossing therefore generally improves immediately. At Moyapur and Royapur the natural shallowing at the crossings is undoubtedly aggravated by the collection of rubbish which forms lumps in the channel which are very noticeable at times, particularly at Royapur. Dredgers working at these places, also at Panchpara and Pir Serang, actually have their work hampered by the accumulations of weeds, mats, etc., at the heads of the suction pipes, necessitating the lifting and clearing of the pipes at intervals. The variety of solid rubbish dredged up is surprising, comprising amongst that already mentioned, shot and shells, skulls, timber, stones, brass utensils, etc. and the natural capacity of the river is evidenced by its ability to deal not only with the enormous quantity of sand and silt carried down, but also with this accumulation of solid matter, which, if not removed by the freshets would inevitably gradually fill up the channels.

Regular action at Pir Serang
Pujali usually free of lumps
Lumps at Royapur and Moyapur
Débris lifted by dredgers

Conditions at Moyapur Crossing favourable for an improved bar in dry season.

8. At Moyapur the bar under natural conditions affords less available depth below the datum of soundings during the freshet season than in the dry season, and this is explainable by a consideration of local conditions. The river expands uniformly in width from Achipur Point and there is no contraction at the lower end of the crossing at Hiraganj Point. Above the latter the right or guide bank for the ebb current, trends away from the crossing and so loses its directive effect on the flow of the current to the opposite bank. When the thread of the channel is carried to the lower crossing by the freshet, the lead across the channel is longer and the guiding control of the bank being lost, energy is wasted by the current in endeavouring to force subsidiary blind channels closer to the bank and through the head of Hiraganj sand. Though the current generally is more powerful relatively, the actual erosive effect on the bed on any particular line of the crossing is, therefore, somewhat less than the effect of the flood-tide during the dry

season on the upper crossing where the width contracts, permitting better control and more concentration of the main body of the current.

9. The conditions at the James and Mary Reach are abnormal owing to defective alignment and the actions of the two tributaries, Damodar and Rupnarayan, which enter at the head and foot respectively of this reach. The main body of the Hooghly ebb current under the influence of the swing of Fulta bight tends naturally, when the concave bank is abruptly terminated at Fulta Point, to shoot across river towards the Public Works Department Inspection Bungalow on the right bank between Damodar and Shipganj Points and even with the counteracting influences, this bank at present shows the beginnings of a reverse concave which would develop if the Damodar influence was removed. However the Damodar ebb current issuing from the right bank strikes the Hooghly current at right angles and helped by the secondary current flowing down the back of Fulta sand, guides the channel from midstream back towards the left bank to join the natural flood-tide channel and a double similar concave is here formed. The combined action, with the contraction at this place, scours a hole at Fulta Point, but as the current below has no definite guiding control, shallow water appears during the freshet season, when the natural action of the flood tide is unable to disperse it. When the Hooghly freshet is very strong, the whole channel is naturally carried to the westward where the ebb spends its energy cutting into the edge of Shipganj sand and in endeavouring to force passages through the head of the Nurpur or Makrapatti sand. Strong eddies are generated in the reach and lumps form in midstream which, generally about September, coalesce with an extension of the tail of the sand lying close inshore below Fulta Point, and this forms a bar running diagonally across the river. The depth on this ridge is very uneven and as the freshet channel widens, it is thrust in towards the left bank and when the conditions are very bad, joins the flat on this side. With the increasing strength of the flood-tide, the channel improves and is usually clear again in December.

Conditions in James and Mary Reach.

Formation of Ninan Bar in freshets

10. The Eastern Gut Bar is chiefly due to the antagonistic action of the flood current, but there are other predisposing causes In the first place the even flow of the ebb current is broken by the protrusion, though slight, of Nurpur Point and this further weakens an already enfeebled current in the dry season which results occasionally in the formation of shallow water in Nurpur Reach Secondly, the outflow of the Rupnarayan at right angles directly opposite the bar, has the effect of damming back the Hooghly current to some extent and the relative effect is greater in the dry season owing to the large tidal basin of the Rupnarayan Principally however the flow of the flood-tide across the ebb channel tends to push the head of the Hooghly sand into the Eastern Gut In spite of these opposing influences the ebb current is powerful enough in the freshet season to force a channel through the 18 feet bar and the Eastern Gut usually remains open till the end of November Subsequently the bar forms again and rises naturally to its worst condition at the end of the dry season from April to June.

Eastern Gut Bar

11. There is an important feature in the development of this bar which should be noted It has been stated that as the flood current increases in power, it carries the head of the Hooghly sand up into the channel, but even during the dry season, there is a downstream prolongation of the tail of the Makrapatti sand to meet it and form the bar. The explanation for this extension of the Makrapatti sand appears to be as follows —The centrifugal force and direction of approach of the flood current raises the level of the river at Fort Mornington Point and at Hooghly Point the level is depressed, resulting in eddy action past the latter on the flood-tide which is the chief difficulty of navigation at the Eastern Gut. The natural consequence of this would be, as demonstrated in 1876, by Professor James Thomson, with reference to all streams, a vortical movement, in which the surface current towards Fort Mornington Point would be changed to a transverse secondary current along the bottom. This would sweep over the Makrapatti sand and meeting the eddy current in Nurpur Reach naturally tend to carry the tail of the Makrapatti sand down and across to the head of the Hooghly sand. The action would be continued at the beginning of the ebb-tide, when the first general movement of the water, owing to the damming effect of the Rupnarayan is, as observed, across the Eastern Gut, parallel to the line of the bar, from the Makrapatti sand to just below Hooghly Point.

12. The Western Gut of the James and Mary Reach is a purely flood-tide channel. The great power and erosive action of the flood current is evidenced in the deep channel scoured out from Fort Mornington to above Hopes Mark, but it is then speedily dissipated and rarely even in the dry season, particularly in recent years when the Eastern Gut has been fairly good, leads a channel of even six feet depth across into the deep water of the Ninan Channel, owing to the long lead for the uncontrolled current.

The Western Gut a purely flood-tide channel

13. The last crossing in the section is at Kukrahati. The combined flow of the Rupnarayan and Hooghly scours out a very deep channel along the right bank below Gewankhali and at the end of the concave bank above Luff Point, the greatest depth in the whole Hooghly is found, reaching to 130 feet below datum. From Luff Point the channel crosses the river in a broad deep stream which usually gives over 30 feet least depth. During the freshet season the tail of the Hooghly sand stretches down, forcing the crossing eastward towards Hospital Point; the great velocity of the ebb current in Hooghly Bight sweeps out heavy material lodged in the deep pool, carries it down and deposits it just out of the direct line of the current below Luff Point. This material is forced down and at the lower end of the reach, accumulates in lumps which, apparently, owing to the action of the flood current, find their way further into

Kukrahati Crossing.

Hooghly Bight, deepest section in whole river

the channel generally about October, before being finally washed away at the end of the freshet season. Samples of the bottom dredged up here show a coarse brown sand similar to that found in the Babla and Ajai with pieces of conglomerate and brick and earthenware two or three inches in lengths.

Variation in river widths

14. The high-water river widths in the section from Calcutta to Kantabaria are very irregular, usually however contracting at the points and expanding in the bights. Though increasing generally downstream, no regular ratio or relation of any sort is observable as will be seen on Plate No. 15. Undue expansions take place at Cossipur and Bral and particularly in Sankrail Bight where the widening is possibly a relic of the old Saraswati river as already mentioned. Considerable widening again occurs at Fulta above the entrance of the Damodar, and lastly, at Diamond Harbour. The least width is at Garden House Point where the river is only 1,200 feet between high water banks while at the Howrah Bridge it is only 1,350 feet. The widths at the points increase generally to 7,500 feet at Kantabaria Point The bight widths increase from 3,750 feet at Cossipur to 13,300 feet in Diamond Harbour. The curve Plate No. 15, reveals the abnormal regular fall of high-water widths throughout Moyapur Reach which is largely responsible for the bar. The datum widths as will be seen, rise and fall more regularly, the Point widths increasing generally from 1,030 feet at Garden House Point to 6,000 feet at Kantabaria Point. The considerable reduction of datum widths in the bights at Cossipur and Sankrail is worthy of notice.

Least width.

Widths at datum

Cross sectional areas

15. The cross sectional areas vary continuously throughout, according to curvature and width and also at the same place particularly near the crossings according to season. The mean sectional area at datum increases from about 36,000 square feet at the Howrah Bridge, to 70,000 square feet at the Fulta gauges. The high-water sectional area at 20 feet above datum increases from 70,000 square feet at the Howrah Bridge to 150,000 square feet at Fulta. There are striking variations in places particularly at Sankrail where the datum area increases rapidly from 36,000 square feet in the middle of the bight to 87,000 square feet a mile lower down at Munikhali Point and decreases as quickly to 37,000 square feet about a mile below at Pir Serang. The high-water (20 feet) sectional area increases fairly regularly from 60,000 square feet at Garden House Point to 150,000 square feet at Munikhali Point, but decreases again rapidly to 76,000 square feet at Pir Serang.

Abnormal area at Munikhali

16. The fluctuation of sectional area is shown on plate No. 14, where the areas at intervals of 1,000 feet along the river between Cossipur and Fulta have been plotted as curves for the conditions, at datum, 10 feet rise of tide and 20 feet level above datum.

The Estuary

17. In the estuary the river assumes a fairly regular funnel shape, widening out from 1½ miles at Kantabaria at the head, to 13 miles at Saugor. The conditions here alter, the ebb current loses the rigid control of the banks and the flood-tide gains power, the channels consequently lose their fixed character and change incessantly through a maze of sandbanks in accordance with influences which are exceedingly difficult to trace. As a whole, however, the longitudinal section in the navigated channel becomes more even and the least depths on the bars and crossings vary more gradually than in the river proper, the ordinary seasonal alterations being inconspicuous In the upper section of the estuary between Kantabaria and Mud Point the banks still exercise a certain degree of control and the navigable channel has generally clung to one bank, or the other, though the conditions so far as the tidal currents are concerned, are different on either side. Below Mud Point the navigable channel has in the course of time traversed every portion of the river as will be seen on map No 7, though for over a century the outlet has been through Saugor Roads into the Eastern Channel.

Alteration in conditions

Upper Section Kantabaria to Mud Point

Lower Section Mud Point to Saugor

Course of navigable channel Upper Balari Bar.

18. The navigable channel at present after issuing from the narrow neck at Kantabaria, passes through the deep water of Kalpi Anchorage and then trends over the Upper Balari Bar, crossing into the right bank. It is held close to this bank to the entrance of the Haldi river and then passes diagonally across the estuary into the head of Saugor roads. A second or Lower Balari Bar, which is usually no great impediment, forms in the middle of channel when on the right bank. the combined flow of the Hooghly and Haldi scours out the Jellingham Anchorage opposite Mud Point, but at the lower end of this, a bar is now forming at the crossing near the "Anglia" wreck. Further down the bed flattens out, rising gradually to the Gabtola Bar between the two Bedford Sands, before the channel issues into the deep water at the head of Saugor roads. Immediately below Saugor, the Middleton channel forms a ridge of shallow water which is the last bar in the river, the approach channel below gradually deepening outward into the Bay. The sands below Saugor in the approach channels to the Hooghly have a practically permanent character, the movement of the tails seawards being on the whole very gradual, though as pointed out on page 22, there has been a fairly considerable growth in the course of 150 years in one part of the Western channel. The approach channels into the river, known as the Eastern and Western channels on either side of the Eastern Sea Reef, are consequently fixed and provide a good depth into the lower end of the estuary; their use for navigation however depends on their continuations through the estuary and these have for a considerable period favoured the Eastern route, probably owing to its proximity to the head of the Swatch of No Ground with its influence on the tidal conditions. In this section of the river from Kantabaria to the Sandheads, owing to the diminishing proportion of fresh water to purely tidal supply, the ebb current loses its dominating influence and flood-tide channels such as the Balari, become fairly permanent navigable routes. On the opposite side of the river the natural continuation of the ebb channel through the Rangafala, is broken into by the strong flood-tide flow through

Lower Balari Bar

Jellingham Anchorage

Gabtola Bar

Eastern and Western channels

Small proportion of fresh water to tidal supply in estuary

Balari, a flood-tide channel

Rangafala the natural ebb channel

Channel Creek which strikes across it, confusing the channel tendencies above the outlet into the Jellingham Anchorage. *Channel Creek.*

19. The conditions at the entrance of the Hooghly with deep approach channels leading from the Bay into a natural funnel shaped estuary, are very favourable for the satisfactory propagation of the tidal wave. The mean tidal range of greatest ordinary springs at the Eastern Channel light vessel is about 8′ 0″. In perigee springs in March 1910, a maximum range of 10′ 10″ was observed and the greatest maximum range would probably be 11′ 3″: the mean neaps range is 4′ 6″. At Dublat, at the southern end of Saugor Island and at the beginning of the estuary, the mean range of greatest ordinary springs increases to 14′ 3″ and mean neaps range to 6′ 6″. The tidal range increases till at Diamond Harbour above the head of the estuary, the mean range of greatest ordinary springs is 15′ 9½″ and the mean neaps range is 7′ 3″. This remains unaltered to Hooghly Point, above which place the tidal wave commences to decrease, till at Calcutta, the mean range of greatest ordinary springs has fallen to 11′ 8″ and the neaps range is about 7 feet.

Favourable tidal conditions in estuary.
Range of tides Eastern channel.
Saugor
Diamond Harbour
Calcutta

20. The range decreases more rapidly above Calcutta and at Gauripur during perigee spring tides in the dry deason of 1917, the greatest range was only 9′ 4″, which was reduced to 5′ 11″, 10½ miles higher up at Dumardaha. At Kalna the maximum range was 2′ 4″ which was practically maintained to Nadia where the range was 2 feet. Above Kalna, however, the actual tide wave entirely disappears, the rise and fall of water-level being apparently due solely to the backing up of the small fresh water discharge.

21. The spring high-water line in the dry season when the tidal effect is uncomplicated by the freshets, rises gradually from the Eastern Channel and more rapidly in the estuary, till it reaches its maximum height usually at Hooghly Point, from where it falls steadily to the actual tidal limit at Kalna. Above Kalna the high-water line apparently rises owing to the backing up of the discharge. *Spring high-water line*

22. The spring tide low-water line falls gradually from the Eastern channel, till it reaches its lowest point at about Balari · it then rises gradually to Hooghly Point where there is a sharper slope to Fulta, after which it rises fairly steadily to Hooghly. There is then a sharp rise to above Dumardaha and the line subsequently flattens out to the tidal limit. In neap tides the high-water has a flatter slope, but again reaches its highest elevation at Hooghly Point after which it falls very gradually up the river. The neap tide low-water line is lowest between Haldia and Balari and then rises very slowly right up to Hooghly and again takes a sharp upward turn from there to Dumardaha.

Spring low-water line
Neap high-water line
Neap low-water line

23. Owing to the depth of water and small range it is difficult to obtain satisfactory tidal observations at the Eastern Channel, but according to some taken in January and March 1910, the average rate of travel of the foot and head of the tidal wave to the Upper Gaspar was about 50 miles an hour. Between the Upper Gaspar and Khijiri at the entrance of the estuary, the foot of the wave is retarded considerably and only moves at a rate of 12·8 miles an hour, while the head of the waves travels 20 miles from Khijiri to Balari the average rate is accelerated to 15·4 miles for the foot and 35·3 miles for the head of the wave. Between Balari and Hooghly Point, the conditions are reversed and the foot of the wave travels faster than the head, the respective rates being 18·8 and 15·4 miles · from Hooghly Point to Moyapur the foot of the wave slackens speed to 12·8 miles and the rate for the head of the wave is accelerated to 23·1 miles an hour and betweeen Moyapur and Calcutta the average rates are, respectively, 15 miles and 21·4 miles.*

Rate of travel of tide wave
At entrance of estuary
Head of estuary
Outlet of river proper
Hooghly Point – Moyapur

24. Above Calcutta the progress of the foot of the wave during the dry season is gradually retarded, slowing down from 14·3 miles between Calcutta and Konnagar, to 13 miles between Konnagar and Gauripur. The average rate is further decreased to 11·3 miles between Gauripur and Dumardaha and then remains unaltered to Kalna, above which place the rate is about 9·8 miles an hour to Nadia. The movement of the head of the wave is more irregular. It slows down to 11·5 miles an hour between Calcutta and Konnagar, but travels at the faster rate of 17·1 miles between Konnager and Gauripur. It is retarded to 10·5 miles between Gauripur and Dumardaha and accelerated to 15 miles between Dumardaha and Kalna From Kalna to Nadia the rate drops to 9·5 miles, but in neaps the average rate between Dumardaha and Nadia is only about 8·6 miles an hour.

Calcutta to Konnagar
Konnagar to Gauripur
Gauripur to Dumardaha.
Kalna to Nadia.
Head of the wave travels more irregularly between Calcutta and Nadia.

25. The period of the flood-tide from low-water to high-water decreases in its progress up the river. The interval is invariably shortest at height of spring tides and longest in neaps. At Phuldobi or Khijiri, the period varies usually from 5 hours in springs to 6¼ hours in neap: At Balari from 4 to 6 hours and at Diamond Harbour from 4 to 5¾ hours. At Hooghly Point the intervals are longer, being from 4¼ to 6¼ hours. At Moyapur the period is from 3¾ to 5½ hours, while at Calcutta it is only from 3 hours to 5¼ hours. During the freshet season the interval is somewhat longer in neap tides Above Calcutta to Nadia, there is not much change in the period of flood-tide during the dry season, the interval being about 3¼ to 3½ hours, or generally longer than at Calcutta during springs, and shorter in neaps when it is about 5¼ hours. The ebb tide interval from high-water to low-water varies from 6¼ hours in neaps to 7¼ hours in springs at Phuldobi. At Calcutta the period is 7 to 9 hours in the dry season and 8 to 9½ hours in the freshets. †

Period of flood-tide from low-water to high-water Shortest in springs and longest in neap tides
Period of ebb tide from high-water to low-water Longest in springs and shortest in neaps.

26. The flood current at Hooghly Point during the early part of the dry season from January to March, runs up river on the average for ¾ hour after high-water, the period of flow being shorter, in spring tides, or half an hour, and longer in neaps when it runs for nearly an hour. The period increases at the latter end of the season in May and June, when the current runs up for nearly an hour after high-water on the average, varying from about ½ hour in springs to 1¼ hours in neaps. At the height and the

Duration of flood current at Hooghly Point.
Longer in May and June

* These rates are averages, the actual movements of the wave on different occasions being very irregular.
† Plate No. 19.

Shortest from September to November. *Duration of high-water slack.*

[illegible] of the freshet season, from September to November, [illegible] the average for a little more than ½ hour, the period varying between [illegible] hour in springs and neaps. There is an average interval of about 35 [illegible] water after the current has ceased flowing, though at times in the neaps, the [illegible] to an hour and during springs it is curtailed to fifteen minutes.

Duration of ebb current at Hooghly Point. *Duration of low-water slack.*

27. The ebb current at Hooghly point runs down on the average for an [illegible] low-water in the freshet season, the interval varying between half an hour and one and a half hours. In the dry season from March to May, the downflow after low-water averages about 35 minutes varying from about 25 minutes in the first of spring tides, to ¾ hour in the last of springs. Slack water at this time generally supervenes for about ½ hour, sometimes being as short as 5 minutes and lengthening out to ½ hour during neaps. In the freshets there is an average slack water for 25 to 30 minutes after low-tide.

Duration of flow and slack at Calcutta. *No flood current in freshet neap tides.* *Duration of ebb and slack at Calcutta.* *Continuous ebb current in freshet neap tides.*

28. At Calcutta during the dry season from December to May, the total duration of the flood current including the slack after high-water, averages about 5½ hours, but in neap tides it is sometimes increased to as much as 6½ hours, while in springs it is only 4½ hours. During the freshets, the duration of the flood current with slack decreases, till when the river level rises sufficiently, there is no flood current at all during the day in the neap tides, while in springs it runs for 2 to 3 hours including the slack water. The duration of the ebb including slack after low-water, averages about 7½ hours during the dry season, being 6½ hours to 7 hours in neap tides and 7½ to 7¾ hours in springs. During the freshets for days continuously in the neaps, the current will flow downstream, or remain slack during the flood period.

Current velocities. *Maximum velocities in Hooghly Bight.*

29. The velocity of the current naturally varies considerably with the state of the tides and season. Both flood and ebb currents attain maximum surface velocities of 5½ to 6 knots an hour in the channel during high spring tides and in Hooghly Bight, rushes of even 7½ knots on the flood and 9 knots on the ebb, were observed off Luff Point at the height of the freshet season in 1904 when tests were carried out in connection with the Puppy's Parlour scheme.

Bore.

30 During high spring tides in the dry season and also in the freshets, as the foot of the wave is retarded between Hooghly Point and Moyapur, the advancing face of the wave becomes steeper until a bore is occasionally created. This usually makes its first appearance on the Brul sand, but increases in height over the Hiraganj sand below the Moyapur Bar. It rushes over the sands between Moyapur and Chinsura with a height of four to five feet, disappearing as it passes into the deeper water of the crossings.

31. Statements attached give detailed particulars of the tidal effect on the river level at various places. It will be seen that the lowest low-water levels recorded since 1875 as referred to datum (Kidderpur Old Dock Sill) were, – 2′ 4″ at Khijiri, – 1′ 1″ at Balari, – 8″ at Hooghly Point, + 11″ at Moyapur and + 1′ 10″ at Kidderpur. The highest high-water levels (excluding cyclones) were 20′ 6″ at Khijiri, 21′ 7″ at Balari, 21′ 11″ at Hooghly Point, 22′ 2″ at Moyapur and 24′ 0″ at Kidderpur. The maximum ranges recorded were 20′ 3″ at Khijiri, 20′ 3″ at Balari, 20′ 3″ at Hooghly Point, 17′ 10″ at Moyapur and 16′ 1″ at Kidderpur These maximum ranges, except at Kidderpur, were all recorded at the height of the freshet season when the effect of the equinoctial tides is enhanced by the backing up of the fresh water discharge. The actual tidal effect on the channels is greatest in February, March and April, when as will be seen the ranges are relatively great in the absence of any fresh water head.

Diurnal inequality of tides. *Mean river-level curves.* *Mean neaps river-level approximates to mean sea-level, in dry season.* *Effect of change of monsoon.*

32. The tides in the river are considerably affected by a diurnal inequality, the night tides being a foot, to a foot and-a-half higher than the day tides in the dry season and *vice versâ* in the freshets, when the day tides are the higher, though not to the same extent. This feature accounts for the vibratory forms of mean river-level curves reproduced on plate No. 10. These curves show clearly the effects of the fresh water-supply and also of tidal influences on the river at Nadia, Palta, Calcutta and Phuldobi. It will be noticed that the curves fall irregularly from the height of the freshet season till, at the beginning of January, the river has the same mean level from Calcutta down, during neap tides and this has fallen to the same plane as mean sea-level. Thereafter till the end of April, the level is affected simply by tidal influences, the fresh water discharge being inappreciable. In 1917, for which dry season the curves are shown, a cyclone occurred at the beginning of May, bringing down the first augmentation of fresh water supply, but usually the practically pure tidal influence is continued till later in the season or, early in June. The mean level of the river, however, is gradually raised through another cause. Plate. No. 7 shows the variation in mean atmospheric pressure over the Bay. It will be seen that the seasonal range of the barometer is greater at the head of the Bay than over the southern portion. The pressure is greatest in the cold weather and falls gradually till September, and the relative difference over the northern and southern limits of the Bay decreases 0·4 of an inch between December and May. This would correspond to a difference in sea-level of about 6 inches and would result in a natural heaping up of the water in the upper portion of the Bay, which would be augmented very considerably by the change in the direction of wind from north-east to south-west. As a consequence of this, the river-level begins to rise from its lowest stage in February, the effect on the sea-level at the Sandheads being increased proportionally up the estuary. The two factors exercising a considerable influence on tidal action, that is the change of the monsoon, and extreme dryness of the season equalising the levels throughout the river, coincide with the equinoctial tides of March. A reference to Plate No. 10 will show how considerably the tidal [illegible] the mean river-levels. The curves all assume a fairly regular wavy form, the [illegible]

[illegible] corresponding with the heights of spring tides. This influence is even noticeable at [illegible] at the height of the freshet season.

33. The rise of mean river levels indicates that the Hooghly is gorged up during spring tides, and the effect is very noticeable in the curves during the dry season when probably practically the whole fresh water discharge is ponded up in spring tides, the channel acting as a reservoir. *Gorging up of Hooghly in spring tides*

34. Plate No. 7 has been prepared to show the varying effect of the fresh water supply on the Hooghly at Calcutta since 1882 and may be taken as a freshet curve depicting the magnitude and duration of the freshets since that year. It has been obtained by meaning the high and low-water levels at Kidderpur separately for each complete lunation from New Moon to New Moon, grouping all the lunations having their middle period in each month together and plotting the results as curves. From these calculations, it appears that the general mean river level at Kidderpur for the period, was 10' 7" above datum, the general mean high-water level was 15' 1¼" and the general mean low-water level, 6' 0" giving a general mean range of 9' 1¼". In a normal year the monthly mean river level is lowest about the middle of February when it stands at 8' 4". The level then rises gradually, owing to the causes already given, to 8' 7½" in March and more rapidly with the increasing strength of the South-West Monsoon and occasional rainfall to 9' 2¼" in April. It rises successively to 9' 8¼" in May and to 10' 6" in June. From about the middle of June to early in July, the freshet discharge comes down the feeder rivers and the mean river level in the latter month is raised suddenly* to 12' 2¼". In August the height is augmented to 13' 10½" and it reaches its culminating point of 14' 1¼" in the middle of September. The mean level then commences to decline and falls to 12' 3½" in October, to 10' 3¼" in November, 9' 1¼" in December and 8' 6" in January. The mean level is therefore above the average for about 4¾ months in the year from just after the middle of June to the first week in November. *General mean river level at Kidderpur and mean range* *Rise and fall of monthly mean river level*

35. It will be noticed in plate No. 10 that the average mean river level at Phuldobi rises from 7' 3" in February, to 10' in September. The mean level at Kidderpur rises from 8' 8" in February, to 10' 4¼" in the middle of June, before the freshets appear in the river: the accumulation of water at the head of the Bay owing to the South-West Monsoon and contributory local rainfall, would, if there was no supply from the Ganges, continue to raise the level, probably to 11' 2", the remainder to the height of 13' 10¼" would therefore be the effect solely of the supply through the feeders that is the freshet would be responsible for raising the level at Kidderpur 2' 9" and other causes raise it 2' 6". *Relative effects of change of monsoon and freshets on mean river level at Kidderpur*

36. In a normal year the mean low-water level is lowest in February and March at 3' 10" and 3' 10½" above datum. It rises 5¼" in April, 9" in May and 10¾" in June, when it stands at 5' 11½". From the middle of that month to the middle of July, it jumps to 7' 6¼" and to 9' 1" in August and reaches its maximum height of 9' 5½" in September. The low water mean level then drops to 7' 9¼" in October, 5' 11" in November, 4' 10" in December and to 4' 2½" in January. *Rise and fall of mean low-water level at Kidderpur*

37. The mean high-water level is lowest in January at 12' 9¾" above datum. It rises gradually to 12' 10½" in February, 13' 4 " in March, 14 feet in April, 14' 4¾" in May, 15' 0¾" in June and then jumps to 16' 11¼" in July and again to 18' 7." in August; in September it reaches its maximum height of 18' 9" and then falls to 16' 9½" in October, 14' 7¼" in November and to 13' 5¼" in December. *Rise and fall of mean high-water level at Kidderpur*

38. The mean range of the tide is therefore normally least in December and January at about 8' 7" and greatest in March and April, and August and September at about 9' 6".

39. The effect of a normal freshet at Calcutta appears to be that it backs up the water level at high-water to about the same extent as it raises the low-water level, so that the range of tide is practically the same as it would be under ordinary conditions at that time of the year. Above Calcutta, however the rise of the low-water level is steeper and in great proportion than the backing up of the high-water, so that the tidal range decreases and in neap tides at the height of the freshets, the wave is damped down till it dies out just above Dumardaha · in spring tides at this time, the tidal influence is naturally stronger and travels further up the river, especially in weak freshets and conversely the damping down effect on the tide wave by a high freshet, naturally extends further down the river, as is shown by the mean range of 8 feet only at Calcutta in September of that abnormally high year, 1894. The tidal head of the river therefore oscillates each year ordinarily between Kalna, the position in the dry season, and just above Dumardaha, the position in neap tides at the height of the freshet season. *Effect of normal freshet on tides at Calcutta and Upper Hooghly.* *Tidal head in freshets* *Seasonal oscillation of tidal head of Hooghly.*

40. Plate No. 11 shows representative lines joining points of high and low-water in the river during high springs, low neaps and mean tides in the dry season. It will be noticed that the neap tide low-water lines intersect the spring tide low-water lines between Konnagar and Palta.

41. The general indications given by the above consideration of the tidal conditions of the Hooghly, appear to be, first, that the wave is considerably obstructed at the entrance of the estuary, and subsequently the movements are irregular owing to the undue expansions at Diamond Harbour and other places. The foot of the wave is unnaturally retarded [illegible] Hooghly Point, where it is affected by the sharp rise of the low-water line. This [illegible] chiefly due to the great bend and shallow water at the James and Mary and [illegible] of the confluences of the Rupnarayan and Damodar. The head of the wave is [illegible] unnaturally between Calcutta and Konnagar, and the abnormal rise of the [illegible] above [illegible] is reflected in the retardation of the movement of the wave

Effect of Jubilee Bridge.

above that point. It is a curious fact that Jubilee Bridge [illegible] that large quantities of stone were thrown at the bases of the piers to [illegible] scour, thus adding to the obstruction to the free propagation of the tidal [illegible] where the river was already unduly narrowed, but unfortunately there are [illegible] the tidal conditions in this section before the bridge was built, to establish [illegible] tion the partial responsibility of the bridge for the defective tidal conditions. In the natural state there would probably be a rise in the low-water line owing to the tidal head of the river reaching down to Dumardaha, but there seems reason to believe that this has been enhanced by the obstruction at the bridge. The question can, however, be settled by a series of observations near the site, which it would not be difficult to arrange.

Effect of gorging in spring tides shown by the rise of spring low-waters above neap low-waters above Palta.

42. Reference has already been made to the gorging up of the river in spring tides and this is borne out by the unnatural rise of the spring low-water line above the neap low-water line from Palta upwards, showing that the river above that point is incapable of discharging the spring inflow quickly enough.

Tidal conditions of Rupnarayan and Damodar.

43. Very little is known of the tidal conditions of the tributaries of the Hooghly. The tidal limit of the Damodar is apparently a few miles above Amta and of the Rupnarayan about twelve miles above Bunder, up the Selai and Dalkhisor rivers. The Rupnarayan undoubtedly influences tidal conditions in the Hooghly considerably, as its mouth lies directly open to the tidal flow with a deep water entrance, so that a great portion of the flood tide passes into it. Above the entrance, the river expands into a wide shallow basin, which though acting as an admirable tidal reservoir for the Hooghly estuary serves by the want of depth, to check the Rupnarayan wave and its further progress up that river is impeded by shallow water and sharp bends. The tidal wedge, or reservoir of the river when the current ceased to flow in at the entrance, on the 24th February 1917, corresponding to a day of high spring tides in the dry season, comprised about 340 million cubic yards. On the same day the tidal capacity of the Damodar was about 35 million cubic yards. The Haldi tidal limit is about 8 miles above the junction of the Kosai and Kaliaghai rivers.

Fresh water discharge of Hooghly.

44. The fresh water discharge of the Hooghly at Calcutta consists almost wholly of the supply through the feeder rivers, together with quantity from the main minor affluent of the Upper Hooghly, the Kharia Nadi. The freshet discharge has already been calculated to reach an ordinary maximum rate of 230,000 cusecs, and an absolute maximum rate of about 300,000 cusecs. The total quantity in an ordinary year is apparently about 58,900 million cubic yards and during a year of high floods as much as 68,000 million cubic yards may be discharged. To these quantities 2½ million cubic yards, the approximate total local drainage above Calcutta should be added.

Discharge observations at Garden Reach, Calcutta.

45. Discharge observations taken with batches of floats submerged to six-tenths of the depths to give the mean velocities in the vertical sections,* were taken at Calcutta during the freshets and dry season of 1916 and 1917.

Beginning of freshets 19th July 1916.

46. On the 19th July 1916, the total discharge of the ebb tide at Kidderpur was calculated to be 206,272,000 cubic yards. The total inflow on the flood tide was 99,483,000 cubic yards giving a total outfall for the half day of 106,789,000 cubic yards. The maximum rate of discharge at any time on the ebb tide was 246,617 cusecs and the mean ebb discharge was 209,059 cusecs. The mean rate of outfall was 65,115 cusecs. On the 6th September 1916, at dead of neap tides, at the height of the freshet season when the current was running downstream all day, the total ebb discharge at the lower end of Garden Reach 323,622,773 cubic yards. The maximum rate of discharge was 265,665 cusecs and the mean rate was 197,867 cusecs: there was no flood inflow. In 1917 under the same conditions, on the 10th September, the total discharge was 251,933,000 cubic yards with maximum and mean rates of 193,571 and 138,934 cusecs, respectively. At the end of the freshet season on the 29th December 1917, near the height of spring tides, the ebb discharge was 132,234,560 cubic yards and the flood inflow was 90,322,960 cubic yards, giving an outfall of 41,911,600 cubic yards with a mean rate of 25,765 cusecs. The maximum rate on the ebb was 170,320 cusecs, and on the flood 194,140 cusecs. In the middle of the dry season on the 24th February 1917 at the height of bore spring tides, the total ebb discharge was 174,155,000 cubic yards: the flood inflow was 160,275,000 cubic yards, giving a total outfall for the 12½ hours of 13,880,000 cubic yards, at an average rate of discharge of 8,395 cusecs. The maximum rate of discharge on the ebb was 226,850 cusecs and the mean rate 170,470 cusecs. The maximum rate of flood inflow was 390,637 cusecs and the mean rate 253,066 cusecs.

Height of freshets 6th & 10th September 1916 and 1917.

Termination of freshets, 29th December 1917.

Dry season, 24th February 1917.

End of dry season, 1st June 1917.

47. At dead of neap tides at the end of the dry season on the 1st June 1917, the total ebb discharge was 86,995,000 cubic yards and the flood inflow, 86,660,000 cubic yards, leaving an outfall of 335,000 cubic yards, with an average rate of only 200 cusecs.

Variation of fresh water discharge.

48. From the above figures it would appear that the fresh water discharge at Calcutta increases from practically nothing (200 cusecs) at the beginning of June, to 65,000 cusecs early in the freshets and then to nearly 200,000 cusecs at the height of a moderate freshet. It diminishes to 25,500 cusecs at the end of December and to 8,000 cusecs in February. These figures obtained from a single flood and ebb, however, require a certain amount of correction, owing to the variation of mean river level due to the diurnal inequality.

Correction of measured discharges due to diurnal inequality.

49. On the 1st June, the mean river level rose from 8′ 8½″ to 8′ 11½″ between the A.M. and P.M. tides, showing that a portion of the discharge was being backed up and the actual discharge should have been greater than 200 cusecs. The mean river level was [illegible] 12 feet on the 19th July, so that the discharge of 65,115 cusecs requires no [illegible]

* Observations taken by Mr. B. M. Samuelson on the Irrawaddy and Mr. R. C. [illegible] verified the assumption that, for all practical purposes, the mean velocity on the vertical [illegible]

[illegible] September 1916, the mean level fell from 13′ 5½″ to 12′ 5½″ and the measured discharge of [illegible] cusecs would be somewhat in excess. The level on the 10th September [illegible] was 1½ feet lower at Calcutta and at Nadia it was 4′ 8″ less than on the 6th September [illegible], thus accounting for the smaller discharge of 138,934 cusecs. The mean level fell from 9′ 8½″ to 8′ 11″ on the 29th December 1917 and the measured discharge of 25,765 cusecs was therefore greater than the natural discharge and similarly on the 24th February when the mean level fell from 10′ 3″ to 9′ 10″. In both the latter instances the entrances of the feeders were practically dry, but the general level at Nadia, apart from gorging up effects, was 12′ 4″ at the end of December against 10′ 4″ at the end of the February, showing that there was still an appreciable natural discharge due to percolation from the sodden soil, at the head of the Hooghly in December.

Explanation of difference in discharge on 6th September 1916 and 10th September 1917

Appreciable natural discharge at end of December

50. The maximum rates of discharge at Garden Reach on the ebb tide varied between 125,000 cusecs at dead of neap tides at the height of the dry season in June, and 265,665 in neap tides in September, and it would be greater in spring tides in the freshets.

51. The maximum rates of flood inflow varied between *nil* in September and 390,637 cusecs in bore tides in February. The greater rates on the flood are due to the slopes being steeper and the shorter interval the flood current runs.

Maximum rates of flood inflow.

52. A slope formula cannot be used generally to determine rates of discharge, particularly on the flood-tide, owing to the rapidly varying slopes, but at the time of maximum discharge on the ebb when the slope is fairly settled, approximate results can be obtained. Using the Mississippi formula to check the float observations on the 6th September and 24th February, maximum discharges of 262,560 and 224,343 cusecs were calculated and these figures agree fairly well with 265,665 and 226,053 cusecs, respectively, obtained by the floats.

Slope formula.

Check on float method at time of maximum ebb discharged.

53. Working on this basis, under absolutely maximum conditions during the freshets, with a fall of four inches to the mile, a sectional area of 65,000 square feet and hydraulic depth of 38 feet, the ebb discharge at Garden Reach would attain a maximum of 366,000 cusecs: this rate would of course be exceptional and only obtained at a time when the mean discharge reached the limit of 300,000 cusecs already fixed as the probable limit of discharging rate from the feeders.

Maximum conditions of ebb discharge in freshets

54. An estimate such as that of Vernon Harcourt, of 650,000 cusecs through a channel of 38 feet hydraulic depth and 65,000 square feet sectional area, would require a fall of about 48 inches to a mile, giving a mean velocity of 10 feet a second. This fall in surface slope is obviously impossible on the Hooghly, or in fact any alluvial tidal river on an ebb tide. As low down the river as Calcutta, the maximum slope on the ebb would probably never exceed 5 inches to the mile and 4 inches at the time of maximum discharge. The mean ebb velocity depending on the depth, would rarely exceed 6 feet a second in the Hooghly at Calcutta with its comparatively small mean depths and any increase of mean velocity would require a much greater proportional increase in surface slope. With a mean depth of 38 feet, a slope of 4 inches to the mile would give a mean velocity of about 5½ feet a second, and with the same depth, it would require 12 times the slope, or 48 inches to the mile, to just about double the velocity to 10 feet a second.

Vernon Harcourt's estimate of 650,000 cusecs impossible

Maximum fall in surface slope.

55. From a map by Mark Wood in 1780, the sectional area at Budge-Budge appears to have been very much the same as at present and it is difficult to see how even when the Noaserai branch of the Damodar was open, the mean discharge for any time could have been greater than 400,000 cusecs at Calcutta, and this brings us to the conclusion that the Damodar has never, or at any rate for a considerable period, carried its whole discharge into the Hooghly above Calcutta. In 1823 during the exceptional floods in the Ganges and Damodar, when the low-water at Calcutta was 20′ 6″, the mean discharge must have reached about 350,000 cusecs. This brings us to the question of the present possible diversion of the Damodar into the Hooghly at Kalna It would be obviously impossible for the Hooghly to accommodate an extra flood discharge of 400,000 cusecs, particularly at a time when its own feeders were bringing in 150,000 to 200,000 cusecs. It must, however, be borne in mind that at first at any rate, before the Damodar opened a proper channel from Burdwan, the discharge would spill over the whole country and the rate would be very considerably reduced; in fact, in 1913 when the Damodar poured 150,000 cusecs through Burdwan, this entered the Hooghly so gradually, that the river levels at Calcutta were hardly disturbed. If the left bank of the Damodar could not be held by restoring the breached embankment after the flood had passed and the channel developed, the Hooghly would react by deepening to a certain extent, but if the development was rapid, there would probably be severe flooding, particularly over the country to the westward and below Kalna; Calcutta would also be affected, though the discharge would be reduced by reservoir action in the river above, and spill. At the same time it does not seem probable that the total discharge at Raniganj, would ever be poured through this route, as a small proportion would probably continue to spill southward into the present Damodar and the Rupnarayan.

Sectional area at Budge-Budge almost unchanged since 1780

Conclusion regarding Noaserai branch of Damodar.

56. In any case a consideration of the matter shows the importance of controlling encroachments which tend unduly to constrict the Hooghly channel, apart from the injurious effect these would probably have on tidal action.

Importance of preserving discharging capacity of Hooghly.

57. From the observations it will be noticed that the total quantity of water passing through the section at Garden Reach, down and up on a high spring tide in February, [illegible] range of 13′ 11″ was 334½ million cubic yards and the proportion of the flood inflow to the total amount was 48 per cent. During low neaps in June, mean range 7′ 4″, the total [illegible] water was 17½ million cubic yards, with a flood inflow of 50 per cent.

Total quantities of fresh and tidal water oscillating through section at Garden Reach. Proportions of flood inflow.

This flood inflow was reduced with the onset of the freshets on the 19th July, to ... per cent. of the total amount of 305½ million cubic yards, on a spring tide with a mean range of 12' 2". In neaps at the height of freshets, the flood inflow was 0 per cent. of the total discharge of 223½ million cubic yards, with a mean range of 5' 9" and after the cessation of the freshets on the 29th December, on a spring tide with a mean range of 9' ..., the total quantity of water passing up and down, was 222½ million cubic yards of which the flood inflow was 40 per cent.

Proportions of maximum to minimum fresh water discharge.

58. The fresh water discharge of about 1,500 cusecs at the height of the dry season, bears the following proportions to the tidal water in the ebb discharge at Garden Reach during that period:—1 to 60, average in low neaps, and 1 to 150 in high springs. At the height of the freshets in neaps it is 1 to 0, and the proportion of minimum to ordinary maximum fresh water discharge is about 1 to 150.

Rapid increase of tidal proportion down river.

Flood influx at entrance of estuary.

Decrease at head of estuary.

59. The tidal proportion increases rapidly down the river. Calculating from the sectional area of 1,142,000 square feet at mean tide and a flood current duration of 5 hours, it is estimated that a total quantity of 3,000 million cubic yards passed up through a section at Blacks Point at the entrance of the estuary above Saugor, on the flood tide of the 24th February 1917: the maximum rate of flood inflow would have been about 6,000,000 cubic feet per second. At Kantabaria at the head of the estuary with a flood duration of 4½ hours and a sectional area of 286,000 square feet at mean tide, the total quantity passing through the narrow neck would have been reduced to about 1,020 million cubic yards and the maximum rate to about 1,800,000 cusecs. At Hooghly Point, the flood inflow of about 800 million cubic yards split up and apparently about 340 million cubic yards passed up into the Rupnarayan. At Fulta Point the total inflow decreased to about 405 million cubic yards, of which 35 millions flowed into the Damodar and the balance formed the tidal wedge reaching up to Balagarh where it would have been low-water simultaneously with high-water at Fulta.

Flood influx at Hooghly Point and tidal reservoirs of Rupnarayan, Damodar, and Hooghly above Fulta.

Tidal wedge above Calcutta.

Proportions of fresh to tidal water in ebb discharge below Calcutta in dry and freshet season.

60. At Calcutta the total influx was 160 million cubic yards* which filled the tidal reservoir formed by the continuation of the river channel above Garden Reach on that day. The total fresh water discharge for the 12½ hours of both tides above the Damodar outfall, was only about 14 million cubic yards and there could have been a very small augmentation of this from the Damodar and Rupnarayan below Fulta and Hooghly Points, so that it will be seen that insignificant as the fresh water discharge is at Calcutta at this season, it becomes almost negligible as compared with the tidal inflow of 1,020 million cubic yards at the head of the estuary.

61. Taking the ordinary maximum, combined fresh water discharge of the Hooghly, Damodar and Rupnarayan at the height of freshets at 460,000 cusecs, this would be just about half the mean rate of outflow, at Kantabaria on the ebb tide, and adding the Haldi supply, it would be about 1/6th of the mean rate of ebb discharge at Blacks Point on the high spring tide of the 24th February. The mean rate of outflow on the ebb at Fulta Point on the 24th February would have been about 385,000 cusecs, of which the Damodar would have contributed about 43,000 cusecs of purely tidal water. This rate is about half as much again as the combined, ordinary fresh water discharge of the Hooghly and Damodar at the height of the freshet season.

Extent of tidal influence shown by penetration of sea-water

62. The extent of actual tidal influence in the river, so far as the penetration of sea-water is concerned, can be shown by what may be termed the chlorine test, that is, the increase in the saline constituents, chiefly sodium chloride or common salt, in the solid matter held in solution. From experiments made by Dr. Macnamara, Chemical Examiner to the Government, referred to by David Waldie in a paper for the Asiatic Society in 1866, the general conclusions were "that the influence of the tide is little felt at Chinsura at any period of the year, not much more at Palta except towards the close of the hot season in May and June, when it is decidedly perceptible, though not great, and not only decided, but to a large amount at Cossipur, Calcutta, during the months of March, April, May and June."

Increase of total solid matter held in solution during dry season.

63. David Waldie found that the total solid matter in solution at Barnagur just above Cossipur increased from 12 grains in 100,000 grains on the ebb tide of the 31st August 1865, to 24 grains on the 6th December. On the ebb tide of the 28th February 1866, it was 30 grains and on a spring tide on 2nd May, the quantity was 36 grains on the ebb and 88½ grains on the flood tide, while on a neap tide on the 24th May, it was only 21½ grains. On the 14th June on a spring tide, the quantity held in solution increased from 30½ grains on the ebb, to a maximum of 152 grains on the flood. On the 6th July, the quantity had diminished to the freshet proportion of 31st August 1865, or about 12½ grains and on the 8th August 1866 it was only 8 grains.

Proportion of sodium chloride in total solids

64. On the 2nd May, of the 36 grains found on the ebb, 15½ grains were sodium chloride and of the 88½ grains on the flood, 55½ grains were sodium chloride. In the 21½ grains found on the ebb on the 24th May, about 12 grains were sodium chloride and at high-water there were 19 grains. The saline proportions on the 14th June were about 14½ grains in the 30½ on the ebb, and about 125 in the total quantity of 152 grains at the end of the flood tide.

Proportion of sea-water at Calcutta increased considerably during spring tides.

65. The results show the admixture of sea-water at Calcutta during the dry season, particularly during spring tides, for while the proportion of sodium chloride, or common salt, rose from 12 grains at low-water to 19 grains at high-water on the neap tide of the 24th May, it increased from 14½ grains at low-water to 125 grains at high-water on the spring tide of the 14th June, and while the total quantity of solid matter increased ...

* This is nearly double the flood influx of 84½ million cubic yards in neaps on 1st June 1917.

[illegible] of 5 to 1 from low-water to high-water, the proportion of silt increased [illegible]

66. The proportion of silt carried in suspension in the water of the Hooghly varies [illegible] with the height and strength of the freshets, the position and depth from which the samples are taken and the state of the tide, which all affect the degree of turbidity of the water, so that a very comprehensive series of tests would be required to give a reliable estimate of the mean proportion. So far, all estimates have been based on ridiculously few tests and the results can only be regarded as more or less rough guesses. The first observations for this purpose were taken by Piddington, who in 1842 drew a sample of surface water at Calcutta, at noon on the first day of each month and in 1864 took another series, including a set of samples drawn from 18 feet below the surface. The first set of observations were rather doubtful and gave the greatest proportion of silt at the end of the dry season from March to June, and in the latter month the proportion of 855 grains to a cubic foot, was four times greater than in August, and nearly nine times greater than in October, in which month and November the quantities measured, were least. In the second series the proportion was greatest in August, both at and below the surface, with 492 and 564 grains to the cubic foot, respectively. The quantity of silt carried, was found in the second series to be greater in samples taken from 18 feet depth, than in the surface samples Making the same allowance for the first series, the mean proportion of silt at and below the surface, for both sets during the freshet season, from 1st June to 30th November, was 311 grains to a cubic foot, while the mean proportion for the whole year was 280 grains to the cubic foot.

Silt observations. *Piddington's experiments.* *Silt in greater proportion below the surface.*

67. From records of weekly observations taken at the Calcutta Water-works at Palta in 1894 by James Kimber, Engineer to the Corporation and quoted by Apjohn in his lecture on Silt, the proportion of damp silt in 100,000 cubic feet of water increased from a minimum of 10 cubic feet in January to 33 cubic feet in May. In June the proportion was 56 cubic feet and the maximum quantity of 146 cubic feet was recorded in July, which decreased to 118 cubic feet in August and then successively to 73, 63, 64 and 29 cubic feet in the remaining months of the year The mean proportion during the freshets from 1st June to 30th November, was 87 in 100,000, in surface water.

Results at Palta

68. Mr. Livesay's experiments carried out at different depths in the Bhagirathi on three days in August and November 1893, gave a mean result of 147 cubic feet of damp silt in 100,000 according to Apjohn, corresponding apparently to 518 grains in a cubic foot. From daily tests of surface water at Kidderpur in 1912, John Scott obtained a mean proportion of 125 to 100,000 for the whole year and 115 to 100,000 in the freshets. The greatest quantity was obtained in April and the least in November, agreeing generally in this respect with Piddington's first observations. The general proportion was regarded however as being probably too great and another series referred to by him which were taken more carefully and frequently, gave a mean proportion of 91·5 cubic feet for the whole year and 136 cubic feet in 100,000 in the freshets. In this set, the proportion was least in the dry season from January to May, varying between 35 and 45 cubic feet and greatest in July and August with 215 cubic feet in 100,000

Livesay's experiments. *Scott*

69. A considerable number of observations have been taken at Hooghly Point since 1915. Samples of 1,000 cubic centimetres of water have been drawn at regular intervals at four states of the tide, low-water, half, flood, high-water and half-ebb on each occasion and from depths of 5, 11 and 16 feet. In 207 tests during the freshet months from 1st June to 30th November, the average quantity of dry silt contained, measured 470 grains in a cubic foot and 110 tests in the dry season gave 332 grains.

Observations at Hooghly Point

70. Mr. Apjohn found from a number of experiments, that a cubic foot of damp silt in a firm state weighed 95 lbs., of which 50 lbs. was silt and the remaining 45 lbs. water ; reducing on this ratio, all the estimates to a common basis of grains to a cubic foot, and making the same allowance for mean depth as in Piddington's observations, we obtain the following results —

Reduction of results to common basis.

—	Bhagirathi, Livesay.	Palta, Kimber.		Calcutta, Piddington		Calcutta, Scott		Calcutta		Hooghly Point, Reaks.	
	Freshets.	Freshets.	Whole year.	Freshets	Whole year	Freshets	Whole year.	Freshets	Whole year	Freshets.	Whole year.
Grains in a cubic foot at surface.	333	305	198	238	198	397	437				
Grains in a cubic foot.	518	416	270	311	280½	541	599	477	321	470	400
	Mean depth to 30 feet.	Mean to 18 feet.		Mean to 18 feet.		Mean to 18 feet				Mean depth to 16 feet	

71. The Hooghly Point observations showed that the samples contained a considerably greater proportion of silt during spring tides than in the neaps, even during the freshets. This is due to the stirring up of the deposit on the sands by the stronger action of the current and this accounts for the anomalous results obtained by Piddington and Scott, showing a greater proportion of sediment in the dry season than in the freshets. Mr. Apjohn found this increased silt charge during spring tides very markedly

Silt charge increases in spring tides, particularly in dry season.

shown in rivers connected with the coast canals and in the Hooghly, the proportion of silt determined by him was 18 times greater at the height of spring tides, than it was three days previously and ten times greater at high-water than it was immediately after the flood had made. Mr. Soutter made some experiments on the silt in Tolly's Nullah in 1889 and found that the proportion was about ten times greater during spring tides in May and June, and about three times greater during July and August, than in neaps. This complicates the problem of the actual quantities carried down by the Hooghly, as the tests will probably show an excess due to this cause, and this in a measure accounts for the high mean proportion determined for Hooghly Point, where a greater number of the tests were made in spring tides. The Hooghly Point results also of course include silt brought down by the Damodar and Rupnarayan rivers. Tidal action introduces a further complication, owing to the proportion of tidal to fresh water increasing as the discharge passes down the river, so that the general proportion of silt carried in suspension, is naturally considerably reduced as the silt laden discharge mixes with the purer water brought in from the Bay by the flood tide. Taking everything into consideration, it would appear that the mean proportion through the whole depth, of dry silt carried in the water of the Hooghly at Calcutta, during the freshet season from 1st June to 30th November, will not be less than 480 grains in a cubic foot. This estimate is necessarily a rough one, but will serve to give some idea of the quantities of solid matter carried down annually by the Hooghly. This proportion by weight has to be reduced to measure of volume. Piddington in connection with his experiments, collected some silt from the water filtering tank then at Chandpal Ghat, had it moistened and beaten hard and then dried into the consistency of a sun-burnt brick. He found a cubic inch weighed 424 grains and on this basis converted his mean proportion of solid matter, *including that held in solution*, of 433·6 grains into practically one cubic inch to a cubic foot of water. The sample probably contained a good proportion of sand and there was certainly some moisture. The silt obtained from the samples taken at Hooghly Point down to 16 feet depth, consisted of very finely divided particles of practically pure mud, with hardly any admixture of sand. In a loose state when quite dry, a cubic inch weighed 228 grains, or 56½ lbs. to the cubic foot. When shaken down into a firm compact state, free of granules, a cubic inch of this silt weighed 286 grains, measuring 70½ lbs. to the cubic foot. On this basis the mean proportion of dry silt in the Hooghly at Calcutta during the freshets, would be 1·68 cubic inches of dry earthy matter in a cubic foot of water, or a proportion by volume of 1 to 1,030.

Result of tidal action. *General estimate.* *Reduction to a measure of volume.* *Piddington's determination of weight of damp silt.* *Weight and quality of dry silt.* *Silt contents by volume.*

Suspended matter in Rupnarayan and Damodar.

72. The sediment carried by the Damodar and Rupnarayan in suspension probably contains a larger proportion of sand and would be heavier than the Hooghly silt. The flood discharge of the Damodar is very red and apparently carries a proportion of extremely fine, impalpable sediment so that it is difficult, even by filtering, to get rid of the discoloration in the water.

Solids carried in solution. *Hard crust of sandstone in formation.*

73. In addition to the earthy matter carried in the water, there are solids, such as lime and magnesia carried in considerable quantities in solution. Piddington found a mean proportion of 4·6 of carbonate of lime to 6·0 of earthy matter in the total quantity of solid matter in his samples. In places, the lime apparently combines with the sand and mud to form a hard crust on the bed of the river, covering loose sand deposit underneath. This has been found on the Upper Balari, where the dredger has experienced trouble in breaking through the hard strata and at Shalimar in Calcutta even a bucket dredger has had difficulty in dredging through this crust.

Quality and weight of sand in river bed.

74. The heaviest sand in the Hooghly is that brought down by the western tributaries of the Bhagirathi. A sample from the Babla shows a fairly coarse, gravelly red sand, weighing about 100½ lbs. to the cubic foot when shaken down dry, and the Ajai sand is similar in character. In the Babla sample, all the sand passed through a 20 sieve, 90 per cent. past through a 40 sieve, 35 per cent. through a 60 sieve, while nothing passed through a 100 sieve. In the Ajai sample, 95 per cent. passed the 20 sieve, 60 per cent. the 40 sieve, 35 per cent. the 60 sieve and 4 per cent. the 100 sieve. This kind of sand is, however, seldom met in the channels of the Hooghly, though a sample picked up at Fisherman's Point Anchorage showed traces of it and weighed 100 lbs. to the cubic foot. In this sample, 99·5 per cent. passed through a 60 sieve, but only 33 per cent. through the 100 sieve. The red sand is conspicuous at Kukrahati where 75 per cent of the sample passed the 40 sieve, 48 per cent. the 60, 15 per cent. the 100, and all passed through a 20 sieve.

75. Ordinarily the bars in the river consist of very fine grey sand, similar to that found in Ganges at the Bhagirathi entrance, with an average weight of about 95 lbs. to the cubic foot. In a sample picked up at Narainpur at the Bhagirathi entrance, while all passed through a 60 sieve, only 85 per cent passed through a 100 sieve. In the samples from the Hooghly bars generally, which have a greater proportion of mud, while practically everything except a few flakes of mica passes through a 60 sieve, 93 to 95 per cent. passes a 100 sieve. The quality, however, varies in places. For instance, of two samples picked up on the Upper Balari Bar in different years, while 99 per cent. passed through a 100 sieve in one case, in the other, only 80 per cent. passed through, though in both instances all the sand passed a 60 sieve. In places the deposit sometimes has a large admixture of mud and assumes a very fine powdery form with a weight of 85 lbs. to 87 lbs. to the cubic foot. This has been found at times on the Eastern Gut, Moyapur and Upper Balari bars, and appears also on dry sands, such as at Sankrail. The river bed in the deeper water of channels is also largely composed of pure sand, but in places, the proportion of mud and clay is very considerable in deep water, where at times the bottom is [illegible] clay.

Lighter sediment carried out to sea.

76. The lighter sediment is carried largely out to sea and disseminated over the large area covering the approaches to the river. The deposit on the Eastern Brace Sand at the entrance of the Western Channel, has a large proportion of mud and weighs about 80 lbs. to the cubic foot, while a sample picked up at the Eastern Channel Light Vessel in ten fathoms of water, was very nearly pure Hooghly silt, such as is carried in suspension in the upper layers of water, with 94 per cent. of very fine sand and mud passing through a 100 sieve, and the weight was only 75 lbs. to the cubic foot Further out in the Bay, the deposit is simply ooze.

Quantities of silt carried through each section

77. The quantity of silt carried down by the Hooghly is, therefore, approximately 54½ million cubic yards from the Nadia rivers and 17 millions from the Damodar, Rupnarayan and Haldi rivers, which, with all drainage makes a total amount of about 71½ million cubic yards. Of this about 54 millions is carried past Moyapur; 57, past the James and Mary and 66 millions past Hooghly Point. The total quantity would be a block of dry earth one mile square and about 69 feet thick However, some reduction should be made for silt, trapped for brick making and other purposes. This, though apparently inappreciable, makes a fairly considerable quantity in the aggregate. It settles in the pits to a depth of 2 to 3 feet a season and with a rough estimate from the area covered by silt pits for brick-making, as well as for water-works, a total quantity of one million cubic yards may be abstracted from the Hooghly water in this manner. Considering the almost inappreciable quantity of the total flow which enters the pits, some idea of the total amount of silt carried by the river may be gathered, but each settling ground from Chinsura down, abstracts a small proportion of the suspended matter and helps to clear the water gradually down to Moyapur. The deposit in these pits is mostly pure silt, but a certain quantity of sand is included, which is more prominent at certain times.

Total quantity.

Silt trapped for brick-making purposes

Effect of freshets on Hooghly channels

78. The foregoing physical characteristics of the Hooghly have been examined, so far as information is available, in somewhat great detail as they provide the necessary basis for the consideration of the problem of the effect of the freshets from the Nadia rivers on the Hooghly channels. Opinions have been expressed that the cause of the troubles to navigation in the Hooghly, is the quantity of silt carried into the river during the freshets, so that if the fresh water-supply was excluded, the silt would disappear and the Hooghly channels would automatically improve. This view overlooks the fact that even if it were possible to close the Nadia river entrances entirely, the discharge from the Western tributaries of the Bhagirathi must still find its way down the Hooghly and this constitutes about 27 per cent, or nearly one-third of the whole ordinary supply. the sand and silt from this source is of a much heavier and coarser quality than that brought down from the Ganges, so that the reduced fresh water supply would carry into the Hooghly a heavier proportion of sediment

Impossible to exclude all sources of freshet supply

The suspended matter all carried to sea

79. Suspended matter is at present brought into the Hooghly in very large quantities, but, as has been shown, it is largely mud of very light character and easily transported, so that it only settles in sheltered places and for the most part is carried right out to sea and disseminated over the Bay * The large increase in proportion of tidal to fresh water in the lower reaches considerably reduces the general proportion of the silt charge, as the discharge reaches the estuary and the increased specific gravity of the water enables it more easily than ever to transport and disperse the silt. The sand which forms the obstructions in the channels appears to constitute a very small proportion of the floating sediment and is probably carried in the lowest layers of water, or pushed along the bottom, the water being loaded to nearly its full capacity with silt. This sand itself is of very fine, clean quality and very susceptible to the continually varying actions of the current, so that the moulding and remoulding of the river bed is continually going on, accounting for the frequent and more or less regular changes in the channels of the river proper.

Graphic record of conditions of Hoogaly channels

80. Plate No 16 gives a continuous record for some years of the available depths on each of the crossings and bars in the river It, therefore, constitutes a graphic history of the channels of the Lower Hooghly and apart from other considerations, reveals the general effect of the freshets on the navigability of these channels.

Effect of freshets shown by curves

81. It will be seen that with the exception of the Eastern Gut Bar, the peaks in the curves which correspond to the worst conditions of the crossings, that is when the least depths are available, occur usually in the months of August and September, or at the height of the freshet season; subsequently the curves fall rapidly till the end of the year, but as the dry, or flood-tide, season advances, there is a general tendency for the lines to rise again. Speaking generally, therefore, the ordinary seasonal effect of the freshets is at first to cause deterioration. This seems to be due to the sudden and more or less violent change in conditions and the movement of solid *débris* along the bed of the river from pool to pool. The deterioration in this case appears to be a phase in the development of the channels under altered conditions and is caused, not so much by new deposit, as by the redistribution of material already deposited, as the mobile bed readjusts itself to the change in the forces which act on it. At the latter end of the freshets and before the flood-tide season gains influence, the channels are generally restored to their proper condition. As a matter of fact, the regular changes in the normal river channels of the Hooghly, tempt one to apply the generalization already referred to in dealing with the non-tidal Bhagirathi, paragraph 11, page 34, that the bed rises at the shallow crossings on a rising river and falls with a falling level.

River bed at crossings rise on rising river and fall on falling river.

* This does not mean that every particle brought into the river by the head-waters, is necessarily carried out the same season. In some places silt is deposited and in others, fresh sediment is picked up, so that the general result is the same.

Effect on channel of occasional high freshets.
Conditions at Ninan

82. Though a single very high freshet causes considerable deterioration for the season at various places, such as Matiabruj, Fulta and Ninan, with a succession of high freshets, the navigable channels of the river proper might be expected to improve, with the exception of the abnormal channel at Ninan. This deteriorated, considerably in the high freshet of 1885 and remained bad till 1888, in which year it recovered. With strong freshets in 1889 and 1890, it deteriorated again and remained in very bad condition throughout 1891. It fell again with another high freshet in 1893 and did not improve till 1895, while in the weak freshet of 1896 it was considerably better.

83. On the principle that a chain is no stronger than its weakest link, the navigability of the Hooghly would gain no advantage from the greater scouring effect of high freshets, so long as the abnormality at Ninan caused considerable deterioration in the channel in this section, particularly as this deterioration is greatest at a time when the Eastern Gut Bar in the same section is naturally in its best condition and the seasonal improvement occurs when the Eastern Gut enters on its deteriorative phase, thus giving a continuously bad period for the whole section.

Effect of weak freshet.
Eastern Gut Bar

84. A general disadvantage of very high freshets also, is that a greater proportion of heavier sand is likely under these conditions to be carried down in suspension and this by replacing lighter sand is likely to give trouble in succeeding freshets, particularly in the estuary. Weak freshets, on the other hand, would eventually result in general deterioration which becomes immediately apparent at another link in the chain at the Eastern Gut, which was in a continuously bad condition during the abnormally weak freshet period from 1895 to 1897.

Action of flood current in dry season

85. It might be argued that weak freshets bring a lesser and lighter quantity of silt down the river, but as already seen, the silt is of such light nature that it does not usually settle in the channels. On the other hand, the current in the dry season stirs up the deposit on the sands in the approaches, as well as that in the river, during spring tides, so that the water is then fairly heavily charged with sediment which is heavier than ordinary silt and settles more rapidly.* This, owing to the predominance of the flood-tide, is carried up the river and if the freshet sluice head did not exist, or was not powerful enough to sweep it all out to sea again together with the silt carried in by itself, the river would inevitably deteriorate, as has been shown to be the case with the Rasulpur and certain Sundarbans rivers where the tidal spill which performs the same functions as the freshets, has been restricted.

Deterioration of channels in dry

86. In the curves of available depths, plate No. 16 it will be noticed that the lines usually commence to rise before the end of the flood tide season in June. The normal deterioration of the channels at this time is quite intelligible. The navigable channels of the river proper have, as already stated, been formed in the concave bends by the ebb current and the flood current, vainly endeavours to create new channels along its natural line of flow on the opposite, or convex sides. When the two forces are evenly balanced, or the flood tide predominates, it endeavours to change the established conditions and as there then are no decided channel creating tendencies at the crossings, deterioration naturally ensues, which would become more apparent and serious, if the ebb current failed to receive the regular re-enforcement of the freshets which enables it seasonally to regain control over the conditions.

Permanent regimen of Hooghly

87. The Hooghly has a fairly permanent, general regimen, that is an equilibrium has been established between its sectional area and its power to dispose of the silt carried into it. The quantity of this silt has been seen to be enormous and it is apparent that if even a small percentage of deposit were left regularly in the river each year, this, together with the sediment carried up by the flood-tide during the dry season, would, in a short period give unmistakeable signs of deterioration. With a diminished supply from the feeder rivers, the upper channels would react and the tidal reservoir would be gradually reduced. Now the channels are dependent for their maintenance during eight months in the year on tidal action and any restriction on the up and down sweep of the current would unquestionably be harmful, not only in the estuary where these forces are predominant, but also in the upper channels.

Tidal action

88. Furthermore, as in all tidal rivers, the extra depth given by the rise of tide at high-water, is of the utmost value to navigation, and as a matter of fact, it is only this tidal rise which makes the Hooghly navigable by vessels of deep draft. Any reduction of the tidal reservoir would react on the range of tide in the upper reaches, so that it is desirable to endeavour to extend tidal action as far up the river as possible, both on account of the resulting benefits of increased scour in the channels and increased rise of tide in the dry season. A good freshet, besides its beneficial scouring effect on the channels is valuable to navigation, as it provides increased depth at high and also at low-water, and while very high freshets are undesirable under the present abnormal conditions at Ninan, and owing to the increase in heavy sediment carried down which might be expected to give trouble in the estuary,† very low freshets on the other hand, cause similar acute trouble at the Eastern Gut Bar and a continuance of them would result in general deterioration.

Moderately good freshets beneficial. High and low freshets undesirable

Finally, the exclusion of the Ganges freshet altogether and reliance chiefly on tidal action, would gradually reduce the Hooghly to the same condition as the Rupnarayan.

Effect of total exclusion of Ganges spill and reliance on tidal action

* While the water in the Hooghly channels is highly discoloured at the height of spring tides in the dry season, during the weak currents at the dead of neaps, it becomes comparatively clear, the sand and silt stirred up, having been redeposited generally, and higher upstream owing to the stronger force of the flood-tide.

† The disadvantages of high freshets in their liability to block the approaches to the river, are emphasised by the conditions at the outlet of the Meghna, where the combined discharges of the Ganges, Brahmaputra and Meghna fail to scour a continuous deep approach channel through the deposits.

and Damodar. These rivers debouch into the Hooghly near its estuary and so come under somewhat similar tidal influences: as a matter of fact, the Rupnarayan is even more favourably situated in this respect owing to the position of its entrance with regard to the flood-tide. They derive their fresh water supplies from similar basins to that to which the Hooghly would be restricted for its supply, if the spill from the Ganges was excluded, and the class of sediment carried down would be very similar. The conditions being parallel, the Hooghly with the entrances of the feeder rivers from the Ganges closed entirely, might be expected gradually to accommodate its channel to the diminished supply and ultimately to reach the same state of unnavigability as its tributaries. Comparison with Damodar and Rupnarayan

CHAPTER VIII.

Alleged Deterioration of the Hooghly.

AND PROJECTS FOR ITS IMPROVEMENT.

1. As in the case of the Nadia rivers, fears have been periodically entertained regarding the deterioration of the Hooghly, and in fact regarding the closing of this navigable approach for deep draft vessels to the Port of Calcutta.

2. These fears have at various times as in 1853, 1863 and 1895 become so acute as to call for special enquiries into the matter, and as early as 1844, the question of the deterioration of the river had been considered in connection with a proposal to construct wet docks at Calcutta to relieve congestion of shipping in the river. The general consensus of opinion among pilots at that time, was, that while the channels of the Hooghly varied continually, particularly in the estuary, where they were stated to fluctuate between bad and worse, there was no fear that the river would ever become unnavigable by vessels of heavy burden, as one channel opened when another closed. However, in 1853 the the Bengal Chamber of Commerce addressed the Government of Bengal on "the difficult and dangerous state of the navigation of the River Hooghly, which threatens at no distant period to render access to the Port of Calcutta altogether impracticable for any vessels, but those of the smallest tonnage"* Periodic alarms regarding deterioration of the Hooghly 1844. 1853

3. They submitted for consideration "the very great importance of endeavouring to open a new communication from the sea to this Port by some new channel such as the Matla river." The Hooghly Commission of 1853-54, comprising three members, was accordingly appointed to report on the matter. This Committee practically confined itself to the examination of the personal evidence of a number of witnesses and under the circumstances naturally disagreed over the question of deterioration. The majority of two members, while deploring the deficiency of charts and documents and commenting on the contradictory character of the personal evidence, found it "very difficult to understand how a river into the channels of which, like the Hooghly, such enormous quantities of earthy matter are annually poured and deposited, can do otherwise than deteriorate (if totally left to its natural agencies), however gradual or slow the process may be" and supported this view by a comparison of the state of the river at that time, with that shown by certain "Remarks on the sounding of the River by H. Wedderbourne, dated July 8th, 1774, and an "Account of the state of the Channels of the Hooghly" by J. Ritchie, dated December 16th, 1776. They arrived at the following conclusion — The Hooghly Commission of 1853-54 Pessimistic opinion of majority of Committee

"If the statement now submitted by the undersigned be the true exponent of the evidence taken, it follows clearly that the River Hooghly has deteriorated up to the present time: that deterioration has been gradual, and caused by the shoaling and contraction of its deep channels from accumulations of silt; and that under the present conditions of the river, the deterioration will be progressive" They found "that sufficient data do not exist for arriving at an approximate guess as to the period at which ships of large burden may be expected to resort by preference to the Matla, supposing the head of that river to be connected with Calcutta, either by a railway or ship canal, but looking to the immense interests that would be most injuriously effected by such an event, it is very respectfully submitted to the most earnest and early consideration of His Honour the Lieutenant-Governor of Bengal, that every means should be taken to avert such a catastrophe; and the aid of the highest Hydraulic Engineering skill should be called in. Minute and periodical surveys of the whole length and breadth of the River from Calcutta to the Sea, are necessary . . . . . The time may not be very distant when vessels of a class may visit India, for which no probable improvement of the Hooghly would render it navigable; and while, therefore, every nerve should be strained to keep its channels efficient and preserve it as a Commercial highway, it may be well not to lose sight of the Matla as an auxiliary port."

4. The third Member of the Committee, Mr. Piddington, to whom we have already referred, viewed the matter from a more scientific standpoint. He recognised the Optimistic opinion of third member, Mr H Piddington

* The largest vessels visiting the port were then of about 1,800 tons and the most numerous class between 500 and 700 tons.

importance of the freshets in maintaining the channels of the Hooghly and stated "I am of opinion that it is of the highest importance to the future state of the navigation of the river, at least from Calcutta to about Hooghly Point, that the most strenuous endeavours should be made and every means used and every experiment tried, to ensure a copious supply of water for as many months in the year as possible at the heads and along the courses of the three main feeders of the Hooghly."

5. He differed from the other Members on the question of deterioration and arrived at a much more optimistic conclusion as follows :—

> "Reviewing the whole of the evidence, parole and documentary, which we have "obtained and giving every part of it my best consideration, I am of opinion, "that up to the close of the year 1853, there is no fair ground for supposing "that the Hooghly has *upon the whole* deteriorated from Calcutta to the "Sea, as a navigable river during the present century. The changes have "undoubtedly been and always will be frequent, and the permanent ones, "as distinguished from the mere fluctuations of particular channels at "different seasons of the year, are often very great, but not more so than is "to be expected from a tropical river, more or less dependant as the Hooghly "undoubtedly is, on such numerous and variable, and distant elements, as the "seasons and quantities of snow falling and melted on the Himalayas, the "periodical rains of the delta, the capricious formations of the sandbanks "of the Great Ganges at the heads of its feeders, so well described by Major "Lang, the uncertain effects of the supply from its Western tributaries, "and finally, the strength and direction of the South-West monsoon and of "its northerly currents in the Bay of Bengal, on which the strength of the "flood-tides greatly depends. And I fully concur in the view already referred "to, taken by so many of the best informed of the witnesses, that as one "channel shuts up, another opens out, which I think is amply borne out by "the evidence, so that I find nothing to lead us to anticipate any future "deterioration beyond such as may arise from a temporary shallowing of some "of the difficult channels while a change is going on near it, as exemplified "annually in the alternate closings and openings of the Eastern and Western "Guts of the James and Mary"

6 Nothing appears to have been done as a result of this Commission and another critical phase in the channels in the lower reaches again occasioned serious alarm in 1863, and it was reported and published in London that the trade of Europe with Bengal was in danger of immediate and prolonged suspension

> "The calamity which has overhung the city for years, which Lord Dalhousie strove "in vain to avert and the fear of which has at intervals strained and baffled "the ingenuity of half the engineers of Bengal, is officially admitted to be "already at hand."

Leonard's report, 1865

7 In February 1864, the Secretary of State placed Mr H Leonard, Superintending Engineer, Public Works Department, on special duty to report on the river. Mr. Leonard visited all the important European rivers where improvement works were being carried on and consulted Sir Charles Hartley, Engineer of the Danube Commission He submitted a report in June 1865, reviewing the general hydraulic factors concerned in the maintenance of the Hooghly channels and the conditions at the critical points for navigation He agreed with the majority of the 1853-54 Committee, that it is difficult to come to any other conclusion than that the Hooghly must deteriorate, however slowly, considering the agencies at work on the river. "First there is the enormous quantity of silt carried down every year, which must be deposited in or about the debouché, lengthening out the Sandheads and thus decreasing the scouring power of the stream. The process is no doubt very slow, or its effects would be much more marked. Vast quantities of the silt brought down must be carried out far into the deep bay by some agency, very likely during the South-West monsoon when the water of the bay is almost constantly heaped up towards the river, an under current is produced which sweeps it out, but yet the tendency of this enormous deposit of silt is to injure the navigation of the river. Secondly, there is the constant, though slow widening of the lower section of the river, which tends to diminish the scouring power of the current and also leaves more room for the channels to change from side to side". He quoted the opinion of Mr Obbard, the River Surveyor, who had very carefully gone over every document bearing on the point, as confirming the tendency to deterioration Mr Obbard divided the periods under consideration into two epochs, one from 1765 to 1836 and other from 1836 to 1853 A general review of the analysis of the conditions of the channels in the first period, showed that on the whole, there was no recorded proof that the river had generally deteriorated prior to 1836. "Great changes had taken place, especially in the channels between Kalpi and Khijiri where they were almost incessant, but it does not appear me that upon the whole so far as the very imperfect evidence throws light upon the matter, the river was materially better or worse in 1836, than it had been upon the average previously". Of the period 1836 to 1852 Mr Obbard said "Between Mud Point and Kalpi, there can be no question the river has become worse since 1836, and very much worse than it was in earlier times. From Kalpi to Calcutta, the river is neither better nor worse than it has previously been"

Obbard's opinion, 1865

8. With the subsequent opening in 1875, of the Balari channel, which superseded the unstable Rangafala channel, the troublesome section of the river between Kalpi and Mud Point improved. Alarm regarding deterioration of the river was allayed till 1891 and succeeding years, when successive high freshets caused severe deterioration in the Ninan channel at the James and Mary, as referred to on page 96. 1891

9. On the representation of the Liner's Conference and the Bengal Chamber of Commerce, the Port Commissioners obtained the services of the late Mr. L. F Vernon Harcourt, an authority on River Engineering, to report on the Hooghly. Mr. Harcourt spent a month at the beginning of 1896 inspecting the river with its feeders from Ganges to the sea, and in an exhaustive and able report, examined the whole position as regards the capabilities of the Hooghly to furnish an adequate channel to a port of such increasing importance as Calcutta. His conclusions founded on all the evidence available, were distinctly optimistic He stated "The foregoing comparison of the various charts and surveys of the River Hooghly, shows that the Hooghly is a fairly stable river, undergoing indeed considerable fluctuations in depth at some places according to the seasons and the volume of the freshets, but free from any general deterioration in its condition between Calcutta and the sea. The Hooghly accordingly, with the exception of the well-known obstacles to navigation at Moyapur and in the James and Mary reach, affords no indication, either in its river portion, its estuary, or its outlets, of progressive deterioration rendering it necessary to contemplate its abandoment as the navigable outlet for the trade of Calcutta at some future period Unless some unexpected change of the course of the Ganges should occur, so as to deprive the Nadia rivers of their annual supply and thereby materially reduce the discharge of the Hooghly, or unless the occurrence of some seismic, or cyclonic disturbance should alter the existing conditions unfavourably, there is every prospect, that provided the two obstructions in the river can be removed and some improvements effected in the estuary, the Hooghly will provide in the future a considerably better waterway between Calcutta and the sea than it has done in the past" L F Vernon Harcourt's report 1896

10. He pointed out that in the absence of improvement works, the Hooghly had provided a moderately accessible water-way up to Calcutta for vessels of larger draft than in former days, but the conditions contributing to this, such as the introduction of steamers in place of sailing vessels and the improved and more frequent surveys of the river, etc., appeared to have been carried to their fullest extent and that further facilities for navigation must be sought in river works He goes on to say "the gradually increased draft of vessels, the extending demands of sea-going trade and the keen and growing competition of ports, have rendered very extensive improvement works necessary for many rivers leading to sea-ports, in order that the trade of the ports on their banks might be maintained and extended by the provision of a safe and adequately deep waterway to them Few ports indeed have been able to rest content up to the present time, like Calcutta, with the many valuable improved indications of the navigable channel, such as the experienced river surveyors of the Hooghly have devised, and the Hooghly can hardly be regarded at all times, as an adequately safe and accessible waterway for the trade of Bengal. Fortunately the Hooghly does not appear to be subject to deterioration, or to present such peculiar conditions as to render it incapable of improvement in accordance with the principles which have, within the last quarter of a century been applied with such conspicuous success to rivers less favourably endowed with natural capabilities for navigation. Rivers with a greater fall than the Hooghly, with more rapid currents, with a less stable bed, with a more irregular flow, bringing down larger quantities of alluvium and devoid of the advantages of a tidal flow, have been improved for navigation, in spite of these disadvantages, and the Hooghly is better adapted for improvement that some rivers upon which successful works have been carried out"

11. He considered that the Moyapur bar had deteriorated owing to the gradual widening of the river at that place, that the changes which have occurred in Fulta Reach—that is, the closing of the secondary channel at the back of Fulta Sand—the widening of the Hooghly in progress near Fulta Point and the prospective reduction in the discharge of the Damodar, appeared likely to constitute a permanent deterioration in the Ninan channel of the James and Mary Reach also that the widening of the river in that reach, afforded less prospect of relief than in former times by the adequate opening out of the Western Gut towards the end of the dry season when the Eastern Gut was bad, the latter, he considered, though the most awkward and changeable part of the river in regard to its bar, is the only portion of the James and Mary Reach which does not appear hitherto on the whole, changed for the worse.

He finally concludes his report as follows —

"In conclusion, a very careful study of all the available charts indicates that the Hooghly possesses considerable natural capabilities for navigation, that by training works in the Moyapur and James and Mary reaches, its river portion could be greatly improved and the deterioration of these two places arrested, and that the navigable channel through the estuary, though less capable of improvement at a reasonable cost might, owing to the fair stability of its course and the run of the currents along the main channel, be deepened to a moderate extent by a powerful suction dredger"

12. Immediately after Mr. Vernon Harcourt's visit, the Ninan channel improved considerably in the weak freshets of 1896, while the Eastern Gut deteriorated abnormally, becoming still worse at the beginning of 1897, when the S.S *City of Canterbury* was wrecked on the Makrapatti Sand. The wreck, however, fulfilled the functions of an Conditions since 1896

isolated mid-river wall and before it sank entirely below the sand, helped to maintain a fair depth over the Eastern Gut Bar. The influence of the wreck was gradually weakening, when the Port Commissioners instituted dredging operations in 1907, by means of which it has been possible to check abnormal deterioration at the critical points, and consequently no further serious deteriorative phase has developed since, in any particular section.

Hooghly subject to deteriorative phases in particular sections.

13. From the general characteristics of the Hooghly, as sketched in the foregoing pages, it will be seen that deteriorative phases may be expected in certain sections of the river, due to abnormal causes in the upper reaches, such as a succession of low freshets, or high freshets, or in the estuary in the ordinary secular development of the channels.* These phases of the channels, which in the past have created alarm, have been shown to be the results, merely of temporary fluctuations and can in no way be taken to indicate general, permanent deterioration of the particular sections, much less of the whole river.

Deterioration at particular points no proof of general deterioration

14. At the same time, Mr. Vernon Harcourt asserted that deterioration of a permanent character had occurred in particular places such as the James and Mary Reach and Moyapur Bar due to the gradual widening of the river through natural erosion. Even, if so, this being due to local causes and not to any general degeneration of the river, is capable of being rectified by the restoration of former conditions at these places, or by improvement works, having the same effect, so that the prospects of the river as a navigable waterway are not necessarily endangered thereby, provided measures are taken to meet this local action at these points and similarly at other places as occasions arise.

Test of expanding trade

15 An ordinary test of the condition of a modern navigable waterway is the limit of its capacity for the traffic of the port If this expands in all directions in accordance with the demands of trade and particularly if difficulties have been experienced in the past, the natural presumption is, that while the river may not formerly have been used to its full capacity, it cannot be deteriorating By this measure the Hooghly is very far from being a decaying river and has so far met growing demands with satisfaction In 1853 when the Hooghly Commission was considering the abandonment of the Hooghly, the largest vessel visiting the port was 1,810 tons

Progressive increase in maximum tonnage of vessels visiting Calcutta

16 The maximum tonnage thereafter increased rapidly to 2,163 tons in 1860, to 3,128 tons in 1870, to 4,023 tons in 1880, to 6,037 tons in 1890, to 7,237 tons in 1900, to 7,705 tons in 1905, to 8,117 tons in 1911, to 9,600 tons in 1914 and 12,989 tons in 1917

Increase in length of vessels

17 The increase in length of vessels has been from 368 feet in 1870, to 400 feet in 1880, 422 feet in 1890, 470 feet in 1900, 501 feet in 1911 and 511 feet in 1917

Increase in maximum draft of vessels

18 What, however, is of greatest importance in this connection, is the increase in the maximum draft of vessels. Previous to 1830, though vessels of greater draft had on occasions formerly navigated the river, pilots were prohibited from moving vessels drawing more than 17 feet, at any time of the year between Calcutta and Diamond Harbour In 1830 a revised rule was issued by which pilots were strictly forbidden on pain of dismissal from the service, from moving a vessel of greater draft than 20 feet, in the river at any time of the year, even with the aid of competent steamers vessels of over this draft had to discharge part of their cargo either at Saugor or Diamond Harbour In 1860 no vessel of over 23 feet draft used the river In 1870, no vessel of over 24 feet draft visited Calcutta and only 4 between 23 and 24 feet In 1880, the maximum draft was 25' 2", and it increased from 26' 1" in 1890, to 27' 2" in 1900, to 28' 3" in 1903, to 29' 3" in 1911 and 29' 10" in 1917 In 1912-13, previous to the war, 49 vessels of over 27 feet and 12 vessels of over 28 feet draft used the river

Factors contributing to increase of size and draft of vessels

19 This great increase in size and draft cannot of course be attributed to any considerable extent to actual improvement of the river channels In earlier times, a large proportion of the trade of the port was carried in sailing vessels and previous to 1830, practically all the traffic consisted of sailing ships and there were only a few tugs

Sailing vessels of former days required better channels than steamers of present time

A sailing ship requires a wider and therefore a naturally deeper channel for navigation than a steamer, and a channel which would barely suffice for a ship of 18 feet draft, sailing up or down the river, might give ample facilities for a steamer of much greater draft, owing to the ability of the latter to navigate along the deepest line or thread of the channel. The supersession of sailing vessels by steamers would, therefore, permit fuller use being made of the available depth and an apparent, though not actual, improvement might result from this cause However, so far as the Hooghly is concerned, this change was effected, so far as the heavier traffic is concerned, some decades ago and the improvement in traffic since about 1880, cannot in any way be ascribed to this cause Another factor, which has contributed considerably to the growth of traffic, is the provision of greater facilities for navigation in the river

Provision of increased facilities for navigation

Better and more frequent surveys

In former times, as shown by the reports of the 1854 Commission and Leonard's report of 1863, the chief difficulty in the river where deterioration was apprehended, was in the estuary This, though to some extent due to the great instability of the Rangafala Channel, the supersession of which by the Balari Channel in 1875, has, since 1879, resulted in considerable improvement in the section, was largely due to inadequate surveys which probably delayed the discovery of alternate routes providing better channels In recent years, owing to complete surveys of the estuary made annually and more frequent ordinary surveys, a closer watch has been maintained, particularly in the transitional periods, so that it has been possible to discover newer routes into which traffic has been diverted immediately the channels have deteriorated, as in 1898 when the old Gabtola Channel was substituted for the Eden. The latter was reopened in 1907 and again replaced by the present Gabtola Channel in

* The navigable channel in the lower portion of the estuary below Mud Point develops at intervals on the eastern side, and then moves bodily westward until it works itself outside the influence of the flood tide from Saugor Roads and then closes, while a new eastern channel is opening

1912. At the beginning of this year, 1918, a new channel was opened to the eastward of the Middleton Channel, as the latter showed signs of general deterioration At the same time the greater frequency of surveys have rendered it possible to take more advantage of existing channels and the provision of additional facilities in the way of plans, buoys, marks and early information of changes, have contributed to the general improvement. This, though Mr Vernon Harcourt in 1896, believed it to have reached its fullest extent, has been considerably extended even since then, and with the institution of dredging operations, has accounted largely for the fact that the Hooghly has been able to meet the growing demands of trade by accommodating larger and deeper vessels progressively. The indications in this respect, though they cannot be taken as showing undoubted actual improvement in the channels, serve to show at least that there cannot yet have been any serious deterioration and this is borne out by an examination of the records.

Examination of conditions in the channels of the estuary

20. First taking the channels of the estuary, the evidence appears to show they have in fact actually improved The Gasper and Thornhills channels, which before the middle of last century corresponded with the present Middleton and Gasper, had according to the evidence of the 1854 Committee, 13′ 6″ and 15 feet, respectively, in 1852 and 1854, though there had previously been better water. Though the channel was well clear in the eighties and has never had as good depth since, the Middleton has only on one occasion, had less than 15 feet (in 1894) and the available depth has been usually 16 to 17 feet, with 20 feet on the Gasper, except between 1900 and 1908 At present there is one bar with 16′ 6″ depth

Gasper, Thornhills and Middleton bars

Lloyds, Eden, Bedfords, Gabtola bars

21 The Lloyds corresponding with the Eden, and the Bedfords with the present Gabtola Channel, which were used alternately, had a best depth on occasions of only 8′ 3″, and 11′ 3″, respectively, the former in 1855 and the latter in 1868 The Eden Channel had only 10 feet in 1888 and though in the transitional periods in 1898-99 and 1912-13, the available depth in either channel was for a short while between 12 and 13 feet, the depth has usually been much greater and at present is 14′ 6″

Auckland, Mud Point, Dredge, and Jellingham channels

22 The Auckland and Mud Point channels which may be taken to correspond with the Dredge and Jellingham channels of recent times, were very variable channels with least depth on occasions reported as 10 to 14 feet in the evidence of the 1854 Committee In 1863, the Auckland had only 13′ 6″ at the same time as the Bedfords had 12 feet, and there was only 15 feet in the Mud Point Channel in 1871. The Jellingham Channel passed through a bad phase between 1892 and 1897, when on occasions the depth fell to 13 feet It has been much better since and at present there is 18′ 6″ on the crossing

Rangafala and Balari Channels

23 The outer and inner Rangafala channels, used alternately, may be taken as corresponding with the present Haldia and Balari channels The inner Rangafala was apparently the navigated channel from the beginning of the 19th century to 1840, when the outer Rangafala, which had been first examined two years before, was opened These channels apparently were very variable and generally obstructed by one or more bad bars, and between 1848 and 1875, when traffic had been generally diverted into the Balari Channel, it seems there was only one year when a depth over 15′ 6″ was obtainable right through On occasions, as in 1859, there was only 9′ 9″ and frequently, as in 1848, 1856, 1859, to 1860, 1863, 1864-65, 1867 and 1873, there was 10′ 6″ to 12 feet The Rangafala island formed between the channels about 1850 and has gradually grown and joined the main land, completely blocking the inner channel, and there is now dry land where the deepest vessels navigated as late as 1862 With the growth of Rangafala island, the Balari Channel on the opposite side of the river gradually opened. The Balari was first buoyed and opened in 1872, with 13′ 6″ available depth, but it gradually deteriorated again and in 1879 gave only 11 feet, but opened to 14 feet in 1880. Since 1888 there has been generally over 15 feet depth in the Balari and in 1917 there was practically a clear 18 feet right through. The present depth is 16′ 6″ The Haldia Channel which forms the lower outlet of Balari, passed through a bad phase between 1893 and 1899 and in the cold weather of 1893-94, the depth in this channel fell to as little as 12 feet, but it opened right out in 1899 and has since then provided more than 25 feet

General comparison

24 The channels in this section, as already stated, pass through great fluctuations, but comparing the general stability of the present channels with a least depth throughout generally 15 feet or more, in the past 20 years, with the condition between 1848 and 1882, when in only one year, 1866, a depth of 15 feet was obtainable right through the estuary, it is obvious there can be no question of deterioration, even allowing for more accurate surveys of the present day This is emphasised by a comparison of the present actual conditions with three stable bars, the Balari giving 16′ 6″, the Gabtola 14′ 6″ and the Middleton 16′ 6″ depths, with the state in 1863, when the Rangafala, Auckland and Bedfords channels were all in a very disturbed condition and provided best depths respectively of only 11′ 3″ 13′ 6″ and 12′ In the worst condition in the past 20 years, which occured in 1899, the Gabtola bar gave 11′ 6″ at the same time as the Upper and Lower Balari Bars provided 14′ 6″ and 16′, respectively

25. As regards the channels in the upper reaches to Calcutta, the Eastern Gut Bar, which till recently was always for about six months in the year, the chief obstacle to navigation, appears undoubtedly to have improved In Pilot Beaumont's evidence in 1854, it was stated as a common fact, that the depth would fall to 3 to 4 feet in March, and the River Surveyor, Mr Bedford, stated the depth varied from 4′ 6″ to 21′ during each year. He gave the monthly means of the depths on the tracks for five years previously, which are summarised in the following table and compared for the months of the deteriorative season, with the mean depths in the 30 years' period from 1875 to 1905, and the 10 years' period from 1908 to 1917.

Mean available depths—Eastern Gut Bar.

—		January.	February	March	April.	May	June.	July.
		Ft In	Ft In	Ft. In	Ft. In.	Ft In.	Ft. In	Ft. In.
1849-53	..	12 5	10 8	9 5	9 4	10 7	6 5	10 5
1875-1905	..	15 3	13 9	12 6	11 9	11 9	11 6	11 9
1908-1917	...	17 0	16 6	15 6	15 0	15 6	15 9	16 0

A mean depth of only 6 feet 5 inches was available in June in the earliest period, but during this month the alternative channel of the Western Gut then afforded 8 feet and the latter may be taken as the mean depth for the month in that period. It will be seen what considerable natural improvement there has been in this channel since 1850, and an examination of the curve of available depths, plate No 16, shows the general improvement since 1875, particularly in the period following on the wreck of the SS. *City of Canterbury* in 1897.

26. Since dredging was undertaken on this bar in 1907, the mean depths are 3 to 4 feet greater in the worst months, than in the intermediate period 1875 to 1905 and 5 to 9 feet greater than in the middle of the century

27. The Moyapur Bar which is the next most important obstacle, shows indications of some natural deterioration which is probably largely due to a local cause, the widening of the reach through gradual erosion From the table of comparison of the mean depths given below, the bar appears to have been 2 to 3 feet better in the middle of the century, than in the 30 years' period 1875 to 1905, except in the worst season when it was only on the average 7 inches better than in the worst season of the latter period It is, however, difficult to reconcile the improved depths shown in Mr. Bedford's table of mean depths for 1849-53, with his statement at the time, that the bar varied between 12 and 21 feet, and Leonard in 1865 gave the depth varying between 12 and 20 feet However, since dredging has been properly instituted, the average depth throughout the year since 1910, is now about 6 inches better than in the middle of the century. Though the bar apparently became worse after the fifties, there can be no doubt there has been some improvement since 1875, as shown in the curves, and it should be noted in this connection that Pilot Keymer in 1854, stated he had known as little as 9 feet on it, while for the past 28 years, the bar has not risen above 10 feet.

Mean available depths—Moyapur Bar.

—		Jan	Feb	March	April	May.	June	July	Aug	Sept.	Oct	Nov.	Dec
		Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In	Ft In
1849-53	...	14 6	17 1	17 7	18 3	18 6	18 0	18 9	17 8	15 11	15 9	13 7	14 4
1875-1905	.	14 3	14 6	15 0	15 3	15 3	15 3	15 0	14 3	13 0	13 0	13 6	13 9
1910-1917	..	19 6	18 0	17 0	16 6	16 3	16 0	17 0	16 9	15 9	17 6	18 3	18 9

28 As regards the Royapur Bar, Mr. Bedford's statement of 1854 is very incomplete. The average depths on all the tracks are given only for the months of May, July, August, September and October, and the best depths are respectively 15′ 7″, 17′ 9″, 18′ 9″, 17′ 7″ and 18′ 3″ For the months of February, March, April and June no depths are given, and in the remaining months, the depths on one or two tracks only and this varies between 13′ 6″ and 14′ 3″, though there apparently must have been deeper water on the other tracks. Leonard in 1865 stated the depth varied with the seasons, but there was generally 16 feet. In 1828, according to Bedford, vessels of 18 feet draft could not pass, but this may have been due to lumps which blocked the channel for sailing vessels The following summary shows the mean depths as given by Mr. Bedford compared with those in the period 1875 to 1905 and 1906 to 1916.

Mean available depths—Royapur Bar.

—		Jan	Feb	March	April	May.	June	July	Aug	Sept.	Oct.	Nov.	Dec.
		Ft. In	Ft. In	Ft. In.	Ft. In.	Ft. In.	Ft In	Ft. In.	Ft In	Ft In	Ft In.	Ft. In.	Ft. In.
1849-53	...	...	...	..	.	15 7	...	17 9	18 9	17 7	18 3	...	...
1875-1905	...	18 3	18 6	18 3	18 3	18 0	17 9	17 9	18 0	17 6	17 3	17 6	18 0
1906-1916	...	19 3	18 3	19 0	18 9	18 0	17 6	17 6	18 6	18 9	19 0	18 9	19 0

29. In 1901 there was an abnormal deterioration in this locality and the depth fell to 7 feet 6 inches in October of that year, but this was a temporary shallowing which shortly after disappeared and was probably due to an accumulation of weeds, or a wreck. It will be remarked that in the last period of 11 years from 1906 to 1917, the depths are on the average a good deal better than in the average in the 30 years period from 1875 to 1905, and apparently generally better than in the middle of last century, this, however, is partly due to occasional dredging when the locality showed signs of deterioration.

30 The Ninan channel occasionally develops a serious bar which was particularly obstructive betweeen 1885 and 1891 and again in 1894 and 1895. In 1890 the available depth fell as low as 7 feet for a short period and was 10 feet, or less, continuously from September of that year till August 1891. It has provided over 15 feet during the past eight years and as will be seen on the curve of available depth, plate No. 16, there are no general indications of deterioration since 1875. As early as 1826, the available depth at times was only about 13 feet 6 inches as shown on a chart made in that year by Captain Ross, Marine Surveyor-General, and Lloyd in 1836 shows 12 to 15 feet. The Ninan lumps were recognised as an impediment in 1853-54 when one pilot stated "in the freshets the Ninan lumps come down and join on the Nurpur lumps, forming a flat which has now (December) 12 feet on it This small water is found from September till the strong floods set in" Apparently, however, deeper channels existed between these detached patches of shallow water and the average available depth was much the same as at present.

31. The Western Gut Bar which was formerly generally used by all vessels in the dry season when the Eastern Gut was bad, has undoubtedly deteriorated *pari passu* with the improvement of the latter Bedford in 1854 gave mean depths fluctuating between 2 feet 4 inches in November and 9 feet 7 inches in March. In the past ten years, the actual available depth has fluctuated between a maximum of 6 feet and a minimum of *minus 3* feet 9 inches. The deterioration of this channel is, of course, of not much actual consequence, as it is only an alternative channel and has never been deep and the deterioration is far outweighed by the corresponding improvement of the Eastern Gut

32 The Eastern Gut, Moyapur, Royapur and Ninan channels are the most important in the upper reaches of the river to Calcutta, but the deeper crossings at Panchpara, Sankrail, Pir Serang and Pujali have assumed greater importance of recent years. These channels were not mentioned as obstructions in early years, but this is because they are low-water crossings and it is natural that with the greatly increased draft of vessels, they should be forced more into prominence. They have rarely afforded less depth than 24 feet at low-water in recent years, and as no vessels of this draft used the river before 1870, they would not have been obstructions in their present state, previous to that date, and may consequently have escaped notice with the few surveys of those times However, in early charts the depth at Panchpara, Pir Serang and Pujali crossings are usually shown between 30 and 36 feet. As will be seen on the curve of available depths, since 1891 Panchpara has seldom afforded more depth than 26 feet, so that, even allowing for difference in the datum of soundings and greater accuracy in recent surveys, there is a probability that some deterioration has occurred at this place, which may be largely due to the greater quantities of rubbish dropped into the river in the port

Conditions at low water crossings

Probability of some deterioration at Panchpara

33 As will be seen on the curve of available depths, Pir Serang deepens at the end of each year to a greater depth than Panchpara, but recently has seldom had as much as 36 feet available depth. In Mark Wood's chart of 1780, the least depth on this crossing is 7 fathoms; in Court's chart of 1814, it is 6 fathoms and Lloyd's chart of 1836, gives 5 fathoms; Laycock in 1875 showed 5 fathoms These depths when reduced to the present datum, would be between about 27 and 36 feet The first notice of shallow water is given in the river plans at the end of 1886, when the available depth was barely 24 feet The curve shows a very gradual deterioration since 1891, till August 1902, when the S.S *Deepdale* capsized in mid-channel The wreck was blown up, but the crossing has been disturbed since: the available depth fell to 17'-6" in 1903 and to 19 feet in 1905 and without dredging operations, in recent years also, the depth would probably, occasionally have been less than 20 feet.

Pir Serang crossing

Wreck of S S *Deepdale*

34. As will be seen, the curves since 1900, allowing for dredging, assume a fairly regular form, showing the normal development of a 24 feet bar at the height of the freshet season. These conditions may possibly have existed in a modified form in earlier years and been missed owing to infrequency of surveys, but considering that vessels in those times had frequently to drop across the channel with their anchors down, the lumps which now form regularly in the crossing, would have proved enough of an obstruction to have attracted notice The deterioration since 1902, is probably largely due to the remains of the wreck, but on the evidence it seems probable that some natural deterioration has also occurred.

Some natural deterioration at Pir Serang

35. The depth on Pujali Crossing in Court's, Lloyd's and Laycock's surveys, varies between 27 and 33 feet, which allowing for difference in datum, is much the same as at present. The curve of available depths shows an improved condition between 1885 and 1895, but this is undoubtedly largely due to infrequency of surveys.

No deterioration at Pujali

36. Previous to 1898, apparently there was a deep channel throughout the year in Sankrail Bight. In that year the depth fell to 28 feet in the dry season and three years later at the end of July 1901, a 24 feet bar formed right across the channel, giving a navigable depth of 20 feet only in the beginning of August. The bar was cleared

Sankrail Bight Formation of 24 feet bar in July 1901

Formation of 24 feet bar at Munikhali Point Crossing

Former bar at Munikhali Point

Natural deterioration in Sankrail reach

naturally by the freshets before the end of the month, but appeared regularly each dry season thereafter, till 1905 and in August 1903 was particularly obstructive with an available depth of only 19′-6″. Shallow water, though not to the same extent has appeared at intervals since then. In 1904, a second dry season obstruction formed at the lower end of the reach off Munikhali Point, and has appeared fairly regularly since that year, giving in July 1910 only 22 feet available depth. Dredging has been necessary at both these places and has checked further deterioration on various occasions. According to Mr Obbard, there was a bad bar across the channel at Munikhali Point in 1795, due apparently to the protrusion of the point, as the shallow water disappeared when erosion occurred at Munikhali Point. There is no further record of shallow water, either in the Bight, or off the Point, and if the depth had ever fallen to 20 to 23 feet previous to 1901, it would scarcely fail to have attracted attention. Deterioration may, therefore, be assumed to have occurred in this reach.

Former obstructions at Diamond Harbour and Hastings

37. On the other hand, mention is made in the evidence of the 1853-54 Committee, of an obstacle to navigation which at a former period existed at Diamond Harbour, and it was also stated that in 1823-26 the river was so shallow opposite Hastings, between Fort Point and Kidderpur, that vessels drawing 15 to 18 feet had to wait for high-water to cross.

Evidence shows that navigable conditions in Hooghly have undoubtedly improved

38. On the whole, therefore, it seems *that so far as the navigable conditions are concerned*, the Hooghly has undoubtedly improved, and particularly since the institution of dredging operations. This is borne out by a comparison of the present state of the river (1st January 1919) when there is one bar in the upper reaches, the Eastern Gut, with 17 feet and three in the estuary, the worst being the Gabtola with 14′-6″ and the Balari and Middleton with 16′-6″ depths at lowest water, with an extract from Leonard's report in 1865.

Comparison with Leonard's statement of conditions in 1865

39. "To state the condition concisely, there are several shoals in the river over which vessels drawing more than 10 feet cannot pass at lowest water, but as this state of lowest water hardly ever occurs, the practical limit of draft at low-water may be taken at 12 feet, unless at very particular times when the James and Mary are very bad. At high-water, neaps, the limit of draft may be taken at 20 feet, while at high-water spring tides, vessels drawing as much as 25 feet may be brought up, but usually 24 feet would be considered the limit."

Improvement due to better conditions in estuary

40. This improvement is, however, almost entirely due to the better condition of the channels of the estuary, and considering the great natural fluctuations which take place in that section, there is no certainty that the present improved conditions will continue indefinitely without some artificial aid; for instance, the natural development of conditions in the upper part of the estuary, might block the Balari Channel and traffic would again be diverted to the unstable Rangafala route, or the shallowing of Saugor Roads might lead to the opening of a middle outlet channel with more liability to disturbance in the lower portion of the estuary.

Some general deterioration in upper reaches

41. In the upper reaches where changes are of a more permanent character and therefore more significant, the only channel which shows an undoubted natural improvement is the chief bar, the Eastern Gut, of the James and Mary. The Western Gut and Moyapur bars show deterioration and the majority of the low-water crossings appear also to have deteriorated slightly. In these cases, this is probably due to a greater or less extent to local causes, such as the widening of the river through gradual erosion.

Indications given by tidal conditions

42. The indications given by tidal conditions must now be considered. A river flowing through an alluvial plain into a tidal sea, naturally tends to raise its slope and lengthen itself, by the deposit along its course and at its embouchure, of the material transported from inland. The limit of tidal influence would travel downstream in accordance with the raising of the natural slope of the river, and the tidal range inland at any port, which is of such great importance to shipping, would in the course of time be gradually reduced, but at the same time, the river as a whole would be in a natural state of growth and perfectly healthy if the low-water slope was not unduly raised. On the other hand, if the low-water slope was lowered, it would indicate that the passage of the tidal wave up the river had been facilitated and consequently the river channels must have improved. The Hooghly fortunately for Calcutta in respect of tidal conditions, has, as already seen in page 22, certain causes operating at its mouth, which restrict its extension seawards, in spite of the great quantities of alluvium carried, and the slope should not have changed appreciably if the river is in a healthy condition. If the river is decaying owing to a deficiency of the supply from the feeders, the process would be most noticeable in the upper reaches and as the reduction of capacity and formation of shoals, would restrict the progress of the tidal wave up the river, the low-water level would rise and the range would be decreased.

Comparison of tidal conditions of Hooghly with Rupnarayan and Damodar

43. For example, consider the conditions in the Damodar and Rupnarayan rivers as compared with the Hooghly. On the 30th September 1916, observations were taken at Kola Ghat on the Rupnarayan about 23 miles above its entrance into the Hooghly and at the Bagnan Bridge on the Damodar, about 17 miles above the latter's entrance into the Hooghly.

44. The low-water slope of the Rupnarayan rose 7 feet 7 inches, or at an average rate of 4 inches to a mile and the range was decreased 4 feet 1 inch. The low-water slope of the Damodar rose 9 feet 5 inches, or at a general rate of 6·6 inches in a mile and the range was decreased 11 feet, or more than half the total range at the entrance. The low-water slope of the Hooghly on that date, between Hooghly Point and Moyapur, a distance of 18 miles, rose 2 feet 8 inches, or at a general rate of only 1·8 inches in a mile

and the range was decreased 2 feet 4 inches. The rate of travel of the tide wave was correspondingly quicker in the Hooghly than in the Rupnarayan and Damodar. The general condition of the Hooghly is much better than that of the Rupnarayan, which is only navigable by deep vessels at its entrance, and far better than the Damodar which is unnavigable, except by small craft. If the Hooghly deteriorated, its tidal conditions might be expected to approximate successively to the present tidal conditions of the Rupnarayan and Damodar rivers. The tidal conditions, therefore, are to a certain extent a measuring rod for the deterioration of the river.

Earliest tidal observations taken by Kyd at beginning of 19th century

45. The earliest tidal observations recorded on the Hooghly are those taken by James Kyd, the famous Calcutta Shipbuilder of the beginning of the 19th century He built the first Dry Docks in Calcutta at Kidderpur, and his observations were taken in connection with this work. The datum used by him was the 'gauge of the river," or lowest low-water, which was 1 foot 10 inches above the zero of the gauge at his dock, which has recently been re-excavated and is now being used as a dry dock for the smaller vessels belonging to the Port Commissioners This zero is the present datum, or Kidderpur Old Dock Sill, so that Kyd's observations require a plus correction of 1 foot 10 inches to reduce them to the present datum.

Kyd's datum.

Comparison of tidal levels at beginning of 19th century with recent data

47. Kyd attached to his paper on the Tides read before the Asiatic Society in 1829, a diagram showing the rise of tide, day and night for a complete year, 1823-24, also diagrams showing the highest rise and lowest fall of tide in each year from 1805 to 1828, and the high and low-water levels at each phase of the moon during 1906-07 and 1825-26 The two latter are replotted and compared with similar curves of recent years in Plates Nos 8 and 9

Lowest low-water level unaltered

48. The first point to be noticed is that the lowest level to which the tide has fallen in recent years, viz, 1 foot 10 inches in 1914, is exactly the same as in the period 1806 to 1828, so that in the hundred years which have elapsed, the actual lowest water-level has not been raised * On the other hand, it will be seen that in the recent period 1894 to 1916, the low-water levels are generally higher throughout, than in the comparative earlier period, 1806 to 1828

Low-water levels generally higher in recent period

Comparison of monthly mean levels of dry

49 The most recent year on which the phases of the moon fall on the same dates as in the dry season of 1823-24, is 1899-1900 Comparing the monthly mean levels in the dry seasons from November to June, when there are no freshets in the river affecting the tides, the following results for the corresponding months are obtained .—

	Mean low-water		Mean high-water		Mean range	
	Ft	In	Ft	In	Ft.	In
November to June 1823-24	4	8¼	14	0	9	4¼
Ditto 1899-1900	4	8½	13	9	9	0½

50 The mean low-water level in the 75 years' period has remained practically the same, being only ¼ inch higher in 1900, but the mean high-water level fell 3¼ inches, reducing the mean range of tide practically 4 inches

Reduction of tidal range due to fall of high-water

51. The maximum range of tide in the corresponding months was 15 feet 2 inches in February 1824, against 14 feet 6 inches in February 1900, showing a reduction of 8 inches due to a lower high-water This is of importance considering the fall of the high-water line from Hooghly Point upwards at the present time, which under proper tidal conditions should not occur

Tidal conditions above Calcutta show greater obstruction to passage of tidal wave in 1917 than in 1896

52 With regard to the conditions above Calcutta, from a comparison of tidal observations taken in spring and neap tides in March and May 1896 and 1917, it seems that the progress of the tide wave has been somewhat obstructed of late years between Calcutta and Konnagar, between Konnagar and Noaserai, the wave has remained regular but in the Upper Hooghly from Noaserai to Nadia, the obstruction to the progress of the wave is undoubtedly greater On both spring and neap tides, the wave in 1917 took 40 minutes longer to travel to Nadia and the flood influence at Nadia was felt from 15 to 20 minutes longer in 1896

Diminution of bores

33 On the other hand, tidal bores which Kyd refers to as an apparently regular and common occurrence in the early part of the 19th century and which were still severe even thirty years ago, are apparently not so common, nor as high at the present time.

Comparison of capacities of river in 1883 and 1917

54. A final test of the deterioration of the river is a comparison of the present capacity with that at a former period The earliest survey which can be used for this purpose, is the regular survey of the whole river in 1882-84 The areas for corresponding cross sections in that survey and surveys made in 1917, in the section between Calcutta and Fulta, have been computed and plotted as curves on Plate No. 14. From this, it will be seen that though the forms of the curves vary, owing to the surveys being made in different months, both for the areas at datum and high-water, or 20 feet above datum, the curves for the earlier period fall generally below the recent curves, giving a balance of capacity in favour of the conditions 35 years ago. This would show that in the upper navigable reaches, the river has shrunk in capacity, though not to any great extent, and this will still be evident throughout, even if the slight improvement in capacity between Calcutta and Barrackpur referred to on page 74 is taken into consideration.

River capacity shrunk since 1883 between Calcutta and Fulta

* One foot ten inches was also the lowest low-water between 1845 and 1853

Effect of reclamations at Calcutta on sectional area

55. In this connection, it may be remarked that in Calcutta, where large reclamations have taken place since 1883 on the Howrah foreshore, the river bed has not reacted by deepening to the narrower width, but the sectional area has fallen throughout. This would show that the reduced capacity suffices for the present discharge, and the former enlarged section was being maintained by tidal action. It would have been naturally reduced eventually, but the process has been hastened artificially by the reclamations.

General conclusions as to deterioration

56. The general result of the consideration of the question, therefore, seems to be, that though the navigable conditions of the river channel have been improved through the local amelioration of the Eastern Gut Bar and the channels in the estuary, the records of depths in the channels of the upper navigable reaches, supported by an examination of the tidal conditions and a comparison of the capacities of the river proper, indicate that there has been some general deterioration in the whole upper river. The process is naturally very slow and has not progressed to any great extent. In its present stage it is not likely to interfere with the artificial improvement of the navigable depth in the crossings, but in view of the generally reduced sectional area at Calcutta, following on a contraction of the river through reclamation, the question of any permanent river works, even though properly designed to meet the local conditions, would have to be very carefully considered as to their general effect on the whole river regimen. The deterioration noticed would probably be the gradual result of a reduction in the fresh water-supply through the feeder rivers.

Freshet curves of present day compared with 1823

57. The mean monthly river levels curve, which may be taken as a freshet curve, for the year 1823, has been contrasted in Plate No 7 with the similar normal curve for the whole period 1893—1917, also for the years 1890, in which the highest freshet of recent years occurred, and 1916, a year of late and fairly high freshet of the present time. The year 1823 was an abnormal year of high floods, culminating in the great Damodar flood at the end of September, which inundated the country and raised the low-water at Calcutta to the unprecedented height of 20′-6″ above Kidderpur Old Dock Sill, giving a range for the day of only 19 inches

Indications of greater freshets formerly

58. In 1823, the high-water sectional area at Calcutta was considerably greater than at present, as in 1794, the river was nearly twice its present width below Fort William. The increased high-water area would accommodate a greater freshet supply, so taking all factors into consideration, the indications point to a more copious freshet discharge at the beginning of the 19th century. This is supported by the fact that the average of the highest low-waters from 1806 to 1823 was about 8 inches higher than the average from 1894 to 1916, and as the freshets chiefly affect the low-water levels, the deduction that the freshets were greater in those years seems unavoidable

59 This is corroborated by the conclusions arrived at with regard to a certain amount of deterioration in the feeder rivers

Importance of maintenance of adequate freshet supply for Hooghly

60. The Hooghly, unlike most great navigable rivers, is not dependent on a fairly invariable normal discharge from its own catchment area suited to its capacity, and the whole argument, therefore, shows the urgent importance of maintaining an adequate supply from the Nadia rivers, not only to permit the Hooghly being improved to meet the expansion of trade, but also to avoid actual degeneration

Projects for Improvement.

Projects for improving the navigable approach to Calcutta 1831—1858

Proposed utilization of Matla, with ship canal to Calcutta

New Port Canning established on Matla 1863

61 It may be of interest to examine the various projects which have been put forward on various occasions for improving the navigable approach to Calcutta The first proposal was to avoid the Hooghly altogether and in 1831, Government ordered a survey with a view to the proposed excavation of a ship canal to the head of the Matla. This scheme has been pressed from time to time attention was drawn to it by the Committee of 1853 and in 1863 a new Port Canning was established on the Matla in conjunction with the Calcutta and South-Eastern Railway. Jetties were constructed, warehouses commenced and the port was opened and used by a few vessels, but owing to various reasons, among them being the financial crisis of 1866, the company responsible for the venture found the scheme unsuccessful, and the port was abandoned. The project of a ship canal to the Matla was again investigated in 1876, but no attempt was made to raise the Rs. 154 lakhs estimated for a canal, 30 miles in length, 250 feet wide and with a depth of 28 feet. The Kidderpur Docks Committee of 1883 drew attention to the supposed advantages of the Matla over the Hooghly, and proposed that detailed plans should be prepared for a ship canal at a roughly estimated cost of Rs. 110 lakhs, when the survey of the Matla then in hand was completed. The present Kidderpur Docks were actually designed by this Committee with a view to their connection with the Matla canal, if necessary. However, a survey made of the Matla river in 1901 by Captain E. W. Petley, R.N., in connection with another scheme for a port on that river, showed that the Matla had deteriorated considerably since 1883 and this has presumably finally settled the question of an alternative route to the Hooghly as the approach to the port of Calcutta.

Ship canal project, 1876

Docks Committee of 1883

Survey of Matla in 1901 shows considerable deterioration of river

Proposed creation of auxiliary ports on Hooghly

62. Attempts have also been made to avoid the difficulties of navigation in the upper reaches of the Hooghly, particularly at the James and Mary, by the creation of subsidiary ports lower down on the Hooghly than Calcutta, the earliest of these being Lacam's still born New Harbour of 1795 at the head of Channel Creek. In 1847 an abortive attempt was made to float a company with capital of one million sterling, with the object of constructing a railway to Diamond Harbour, where it was proposed to establish a port with Wet Docks; and the Docks Committee of 1881 proposed the construction of Wet Docks at

Diamond Harbour, but this suggestion was upset by the Committee of 1883 on whose recommendations the docks were built at Kidderpur.

63. In these cases the question was chiefly one of providing additional accommodation for the expanding trade of the port, though the difficulties and risks of navigation in the upper reaches of the Hooghly were considerable factors in the suggestion for the creation of an auxiliary port. With the recently sanctioned construction of the new King George's dock system connected with the Kidderpur Docks, the whole future trade of the river is definitely located at Calcutta and the problem has been practically confined to one of improving the Hooghly, so as to provide a satisfactory channel for the expanding trade of the port.*

64. In earlier times the chief difficulties of navigation were in the James and Mary Reach and it is on this section of the river that the most attention has been bestowed. The most obvious proposal, to avoid the obstacle altogether by cutting a new channel for the river across Hooghly Point has been put forward at different times and an example is illustrated in Brooks' project shown on Map No. 12. This scheme was put before the United Service Institution in a lecture in 1865 by W A. Brooks, a London Engineer. It provides for a cut from Nurpur across the land to opposite Luff Point and a small groin at Shipganj Point to direct the descending current into the cut. Now it is obvious for any such cut to be successful, it would be necessary to dam the present Hooghly channel below Shipganj Point, which of itself makes the scheme impracticable and even then, the flood-tide would preferably pass up the deep water of Hooghly Bight into the Rupnarayan Furthermore, this cut would not avoid the Ninan Bar, which may be anticipated to form an obstacle, as occasionally at present, above the head of the proposed cut.

Cuts in Hooghly to improve navigation Brooks' project, 1865

65 Another class of proposals favours the diversion of the tributaries of the Hooghly. Piddington in his report of 1854 refers to the frequently expressed opinion that the diversion of the Damodar into the Rupnarayan would lead to the amelioration of the James and Mary, and this view was expressed before the Institution of Civil Engineers by Mr. J Longridge in a lecture on the Hooghly and Matla in 1864. The argument in this case is, that if the influence of the Damodar ebb current was removed, the Hooghly channel would be carried across river from Fulta Point into the Western Gut and this would provide a good navigable route Now it has been shown that the Hooghly ebb current does not naturally strike across fair into the Western Gut, but into the bank above Shipganj Point, from where it is rediverted and its energy wasted, so that in high freshets in the Hooghly, when the discharge is proportionately much greater than that of the Damodar, the Ninan Channel deteriorates Furthermore, in any case, the lead across river here, is apparently too great to enable the Hooghly current alone to carry a deep channel across The only result of the complete diversion of the Damodar into the Rupnarayan would, therefore, be a generally deteriorated Ninan Channel and also a considerable deterioration of the Eastern Gut, owing to the diversion of the current and the restricted tidal flow in the dry season in this section The Eastern Gut has generally been the deepest navigable channel and under present conditions it would seem necessary to maintain the discharge, both tidal and fresh water, of the Damodar opposite Fulta Point and in fact, if possible, to endeavour to improve it, so as to reinforce and guide the descending current more easily into the Ninan and Eastern Gut channels. The diversion of the surplus flood discharge of the Damodar which now enters the Rupnarayan, into the Hooghly at Kalna would, if kept in the channel, unquestionably lead to an improvement of the upper reaches, though severe flooding would probably result. As a great quantity of heavier sand and silt would be carried down however, trouble might be experienced in the estuary of the Hooghly

Proposed diversion of tributaries of Hooghly

Longridge, 1864

66 Leonard in 1865 came to the conclusion that the James and Mary would be considerably improved, if the whole Damodar discharge could be impounded and passed through the Damodar channel at Fulta Point, but he believed that considerable improvement could also be effected by the diversion of the Rupnarayan into the Haldi, as he considered the damming back action of the former river to be the chief cause of the obstruction in the Hooghly above the junction. The great cost of this work, however, rendered it impracticable in his opinion. As the Eastern Gut Bar develops in the dry season when there is practically no fresh water discharge, and the bar is usually scoured through in the freshets when the Rupnarayan is passing its maximum fresh water discharge, the influence of the Rupnarayan in forming the bar is obviously not so considerable as Leonard believed it to have been. To remove its influence altogether, it would be necessary not only to cut an adequate channel for the fresh water discharge into the Haldi, but also to dam the mouth across, so as to cut off the large tidal reservoir of the Rupnarayan and this, if practicable, would inevitably result in the shallowing of Hooghly Bight, Diamond Harbour and Kulpi Roads, while the result on the James and Mary would be very doubtful.

67. The third class of projects is concerned with actual works of improvement in the Hooghly itself, and these may be divided into two sections, training works and dredging The first comprehensive scheme of training works was put forward by Leonard in 1865 He proposed narrowing the channels at Moyapur and Royapur by training walls, as shown on Map No 16, so as to guide the ebb and flood currents on to the middle line of the crossing. At the James and Mary, he proposed a mid-river training wall running down from Fulta Point to about abreast Nurpur Point, to carry the Ninan channel into the Western Gut, with subsidiary works, consisting of a spur

Proposed works of improvement in the river Leonard's project, 1865

* A proposal to provide jetties and coaling facilities in Puppie's Parlour in Hooghly Bight was examined by the Lul Point Commission at the end of 1903, but the project was not recommended

at Fort Mornington Point to prevent so much tidal water passing up the Rupnarayan and to direct more of the flood tide up the Hooghly Channel; protection works on the banks of the Rupnarayan, and the closing of the back channel at the Fulta Sand, by inducing silting by means of spurs. In the same way Diamond Sand was to be reclaimed by bringing out the right bank from Buffalo Point to Horkhali, and by a similar system of spurs, it was proposed to regularise the left bank from Kantabaria Point to Silver Tree Point Leonard preferred longitudinal walls at Moyapur and Royapur, but thought the objects could be attained more economically by throwing out spurs, and apparently all works were to be carried to high-tide level. In accordance with his recommendations, spurs were constructed on both banks at Moyapur about 1870, at a cost of about Rs 2 lakhs and some silting ensued, but apparently before the full effect could have been obtained, the works were examined in 1872 by Mr G. Robertson who condemned them on principle

Robertson, 1872

He believed that harm had resulted through the interference of the left bank spurs with the flow of the flood-tide and these spurs he recommended should be immediately removed; since then all the spurs have disappeared. Mr Robertson suggested a single longitudinal training wall nearly parallel to the left bank and at a distance of about 1,100 yards from it the wall to be 1,500 yards to a mile in length and carried to one-third tide-level and connected with the right bank by a single groin. This was practi-

Sir Charles Hartley, 1865

cally the same suggestion as that of Sir Charles Hartley, who in 1865 proposed a half-tide training wall as shown on Map No 16.

68 With regard to the James and Mary, Sir Charles Hartley recommended an isolated, half-tide training wall in mid-river about 10,000 feet in length, as shown on Map No 13, by which he thought a good navigable channel, particularly in the Western Gut, could be obtained He disapproved of Leonard's spur at Fort Mornington Point and suggested a small work carrying out the bank at this point

Wreck of S S *City of Canterbury*

69 Attention may here be drawn to the beneficial influence on the available depth on the Eastern Gut Bar, by the isolated obstruction on the tail of the Makrapatti sand caused by the wreck of the S S. *City of Canterbury* in January 1897 This is plainly shown on plate No 16.*

Vernon Harcourt, 1896

70 Mr Vernon Harcourt in 1896, proposed to rectify the channel at the James and Mary by a longitudinal, mid-river training wall over 4 miles in length, somewhat similar in position to that of Leonard's and Hartley's combined, starting at Fulta Point and carried down to abreast Hooghly Point, where it was curved round into the point as shown on Map No 14 The wall was to be constructed of fascine mattresses It was to be only 46 feet wide at the base and with a total height of 21 feet, with the top at lowest low-water level, and was estimated to cost Rs. 20½ lakhs. The obvious objection to such a project, is that during the construction of the wall across the only deep water channel, it must necessarily block access to the Port for a considerable period for all deep traffic, and the accumulation of floating constructional material at Fulta Point at high-water would hinder all traffic to a great extent.

Shanghai or Whampoa river training works, 1910. Rangoon river training wall, 1914

71 The only works of a similar character are the Shanghai river training works, carried out about 1910 by Mr. DeRijke, and the Rangoon river training wall constructed by Sir George Buchanan in 1914 The former included a 6,000 feet mattress dam with base width of about 135 feet, across the Ship-channel, and the latter a 10,000 feet training wall of rubble stone dumped on a carpet of mattresses 230 feet in width Both these works were carried up to high-water level and when the Rangoon wall was brought up to near low-water level, severe eddies and whirlpools were generated in the vicinity and deep holes were also scoured inside the wall, owing to the "head" created by the wall causing overfalls This was obviated in the Shanghai works by the simultaneous construction of cross dams, tying the main wall to the bank.

72 In the light of the experience gained by these works, the actual construction and stability of the James and Mary wall as designed by Vernon Harcourt, with a base width of 46 feet would appear to be very problematical and it seems doubtful under the circumstances whether a low-tide training wall would secure the desired results, while a high-tide wall would restrict tidal flow considerably and its cost based on the Rangoon actual net figures, would probably be more than ten times Vernon Harcourt's estimate of Rs. 20½ lakhs

73 To improve the Moyapur Bar, Vernon Harcourt proposed a mattress training wall carried out from the right bank, as shown on Map No. 16, so as to guide the ebb current into the flood channel The top of the wall was to be kept 6 feet, below lowest low-water, in order not to reduce tidal capacity The base width was 52 feet or greater than the James and Mary wall and the cost estimated at just over Rs 5 lakhs.

Lindon Bates, 1899

74 In 1899 Mr. Lindon Bates, an American Engineer, put forward an entirely novel scheme for improving the James and Mary. He proposed abolishing the double concave at Fulta Point and the rectification of the left bank into a single continuous concave, by the excision of Fulta Point from Fulta Creek to Nila Creek, the expansion at this place to be compensated for by training walls on the convex bank, above and below the entrance of the Damodar, which would give a new and better direction to the efflux from that river. This was expected to do away with the Ninan Bar and improve the Eastern Gut, which would be further ameliorated by building out Hooghly Point, so as to carry the deep water along the right bank closer to the deep water below the entrance of the Rupnarayan. He proposed high-tide training walls, enclosing the Brul, Hiraganj and Achipur sands, in order to effect improvement in the Royapur and Moyapur bars and the

* At the end of March 1919, the S.S *Sanctoria* was wrecked in practically the same position, but at a differen angle, and the effect of this wreck will be watched with interest

regularisation of the whole river from Budge-Budge to Hooghly Point to proper ratios of expansion by properly designed training works: tidal regulation works should also be carried out in the Rupnarayan The principles adopted by him, were that no works should be put in on the concave, or cutting bank of such a river as the Hooghly, and all training walls should be carried above high-water level.

75. The estimate given by Lindon Bates for his whole project to improve the Moyapur, Royapur and James and Mary reaches, was only Rs. 75 lakhs, if done departmentally and Rs. 150 lakhs, if he found the money and carried out the works, on what he called the "no play, no pay" principle. Professor Thierry of Bremen generally supported Mr Lindon Bates' proposals, except that he stated that the regulation of tidal propagation which he considered the principal cause of all the troubles, should be done first, particularly in the Rupnarayan, and secondly that no works in the Hooghly should be carried above low-water level. He regarded Mr. Vernon Harcourt's proposed James and Mary wall, as a hazardous enterprise. A great point in Lindon Bates' project for the James and Mary, is that the work could be carried on without blocking, or interfering in any way with traffic on the river, but while it would by rectifying the bank, improve the Ninan Channel and abolish the present difficulties of navigation at Fulta Point, the cause of the Eastern Gut Bar would not be removed, though the protusion of the Point would probably effect some improvement.

Professor Thierry, 1900

76. Mr. Vernon Harcourt read a paper before the Institution of Civil Engineers in January 1905, and the discussion and correspondence, which in many cases condemned Lindon Bates' projects for the Moyapur and Royapur bars, and brought forward modifications of his scheme for the James and Mary, did not produce any original practicable schemes likely to improve the Hooghly at a reasonable cost Two Engineers, Dr Corthell of New York and Mr. Luiggi, favoured reliance on dredging only, to improve the channels in a river of the character and size of the Hooghly

Dr Corthell and Mr Luiggi advocate dredging

77 In 1854 Mr. Piddington had suggested the employment of some plan for stirring the mud and sands at the shallow crossing places, and in 1863 an attempt was made to rake the Eastern Gut and Dredge channels The steamer *Sitang* employed to draw the apparatus, was of only 60 horse-power and could make little, if any, way against a strong tide, but Leonard considered that the results of the experiments showed that shoals could be lowered by this means. On his recommendation, the steam-tug *Agitator* 132 feet in length and of 400 horse-power was specially built to drag one to three rakes over the bars at a fair rate against a four-knot current This vessel was tried on the James and Mary and Moyapur bars from 1867 to 1869, but effected no appreciable improvement Leonard stated that from his knowledge of the river, he was quite convinced that the action of the most powerful dredge would be inappreciable on any of the Hooghly shoals and this was probably quite correct with the dredgers of that period. Mr Vernon Harcourt in 1896 considered dredging inadvisable to improve the condition of the James and Mary Reach, though some improvement might be attained by this means in the channels of the estuary and it might also be employed to assist the training works in the formation of channels in the upper reaches Lindon Bates proposed to combine dredging with his fixed improvement works

Raking and dredging on the Hooghly 1863 *Sitang*

1867-69 *Agitator*

Leonard's opinion on dredging

Vernon Harcourt's opinion on dredging

78. In 1907, the Port Commissioners obtained the *Sandpiper*, a powerful suction dredger, discharging through a floating pipe line and the results proving satisfactory, a self-contained hopper dredger the *Balari* was purchased in 1913. It has been unquestionably demonstrated that considerable improvement can be effected in the upper reaches of the Hooghly by dredging and an improvement of 3 feet in the average depth on the Eastern Gut Bar during the dry season and on the Moyapur Bar for the whole year, has been recorded since the institution of dredging operations and this during a period when the work has been handicapped by having for half the time, only one, and for the remainder, two vessels to deal with all the crossings besides the two bars mentioned The Eastern Gut Bar appears to be particularly susceptible to this treatment and good results have been obtained at crossings such as Pir Serang in the estuary, at the Balari and Gabtola bars, the same measure of success has not been obtained, though the *Sandpiper* contributed materially in opening the new Gabtola route in 1912 and the '*Balari*' opened the upper Balari Bar in December 1917. With the lower bars, which are usually of greater extent, a dredger of the "drag suction" type would certainly secure better results than the "push suctions" of the *Balari* and *Sandpiper* and this point is receiving consideration in the new dredger which is being ordered for the Hooghly to replace one taken over by the Admiralty before completion

Institution of dredging in 1907

79. It is also probable that still better individual results will be obtained, when a definite, scientific, dredging policy, paying due consideration to all the factors of the problem, has been evolved.

From a general consideration of the question, the following points emerge —

(1) The river channel of the Hooghly itself, is the most satisfactory approach to the Port of Calcutta.

(2) The limit of facilities provided for its safe navigation, which have contributed greatly to the expansion of traffic, must now be nearly reached and greater reliance will have to be placed in improvement works in the future.

(3) Fixed improvement works are inadvisible in the estuary owing to the great magnitude of the problem. The permanent improvement works so far proposed in the upper reaches are all open to serious criticism, particularly in the James and Mary section. Fixed works, consisting of bank protection;

some filling out in places where undue erosion has occurred, and perhaps some form of training works at Moyapur and Royapur are all that appear so far to be practicable, or necessary. A suitably placed isolated structure or artificial island, on the Makrapatti Sand in mid-river, with the artificial protusion of Hooghly Point, or the latter work by itself, might be considered as a means of definitely improving the Eastern Gut Bar in order to save a considerable proportion of the present heavy recurring dredging expenses at this place.

(4) A great extent of improvement can be obtained in the upper reaches of the river and particularly at the Eastern Gut by adequate and efficient dredging plant, working on an approved system. By this means, with probably some minor training works as suggested, efficient control could be attained in these channels The problem is a more difficult one in the estuary, but as the flow here is ample and the question is simply one of attracting it into a definite line of channel, a great measure of improvement, sufficient to meet the demands of trade for many years, could without doubt be achieved by dredging, provided the dredgers were of large capacity and of the drag suction type, working on scientific lines.

Hooghly channels capable of considerable improvement provided fresh water-supply and tidal conditions are maintained

80 From the evidence adduced, there appears to have been a certain measure of general deterioration in the Hooghly, which is obscured by local improvements at the chief bars. This has resulted in a certain amount of shrinking of the capacity of the Hooghly, which has been due to interference with the tidal flow, following on a diminution of the fresh water-supply If the process continues, though some improvement of the chief obstacles may still be obtained by artificial means, the limit of improvement, whether by dredging, or river works, will soon be reached.

81. On the other hand, the Hooghly channels are capable of considerable improvement, provided the river is kept in a healthy condition by the maintenance of its fresh water-supply from the Nadia rivers and its tidal volume, the two factors on which it depends for its existence as a satisfactory waterway for deep vessels to the port of Calcutta.

STATEMENT O.

Kidderpur.

Datum, Kidderpur Old Dock Sill.

Year		Lowest low-water	Highest low-water.	Lowest high-water	Highest high-water	Least range	Greatest range
		Ft. In	Ft In	Ft In	Ft. In	Ft In	Ft. In
1875	...	..	..	...	.	. .	.
1876	...	..		. .	...		
1877	..	..	...	.	.		..
1878	.		.	...	.	..	.. .
1879	..		..		.	....	. .
1880		.		...		..	.
1881	...	..	11 7	...	22 7	. ..	.. .
1882	..	2 3	10 5	9 8	22 1	3 10 October	14 4 February
1883	. .	2 3	10 4	9 2	22 1	3 11 August	14 7 March.
1884	...	3 1	10 5	9 7	21 5	4 3 Aug , Sept	14 4 April
1885	...	3 0	12 10	7 9	23 2	2 10 September	14 1 June
1886		2 3	13 8	10 3	23 5	4 2 Sept , Oct.	14 6 February
1887	..	2 11	12 4	10 3	23 2	3 6 September	15 3 April
1888	..	2 8	13 6	9 9	23 2	2 8 "	15 8 ,
1889	..	2 0	13 10	9 6	22 6	2 6 "	14 7 "
1890	...	3 6	13 4	9 3	24 0	1 9 October	13 8 July
1891	..	2 3	11 1	8 11	22 10	2 7 September	14 9 April
1892	...	2 6	11 9	9 4	23 4	3 1 "	16 1 March
1893	...	3 3	12 6	8 7	22 11	1 9 "	14 8 April
1894	..	3 2	13 11	8 11	23 11	1 8 "	13 7 "
1895	..	2 6	10 11	7 10	22 4	2 4 March, Sept	14 4 "
1896	..	2 11	10 6	9 1	21 0	2 9 September	15 3 October
1897	.	2 7	10 8	8 10	21 10	1 11 August	15 1 April
1898	...	3 0	11 6	9 4	22 5	2 5 Aug Oct.	14 0 Apl Aug
1899	...	2 10	11 10	9 6	23 1	2 5 September	14 3 March
1900	..	2 6	13 0	9 8	23 2	4 3 "	15 4 ,
1901	...	2 4	11 1	9 9	21 9	3 6 "	15 7 April
1902		2 9	10 11	9 7	21 6	3 10 "	14 2 May, July.
1903	.	2 5	10 11	9 9	22 0	3 6 ,	14 7 June
1904	.	2 5	11 9	9 8	23 6	3 8 ,	14 10 Mar , Apl
1905		2 0	11 8	9 11	23 0	3 3 "	15 7 " "
1906	...	2 8	12 [illegible]	[illegible] 5	22 7	2 10 "	15 3 May
1907	.	2 6	10 [illegible]	[illegible] 7	22 0	3 1 "	15 3 June
1908		2 5	11 3	9 4	22 7	2 6 ,	15 1 March
1909		2 6	12 8	9 10	•24 0	2 9 October	15 3 ,
1910		2 9	12 1	9 7	22 5	2 1 September	15 1 Apl May
1911	..	2 8	12 3	8 9	23 6	2 0 October	14 5 April
1912	..	2 4	10 9	8 6	21 9	2 6 September	14 2 August
1913		2 5	11 7	9 1	21 11	3 7 "	14 7 February.
1914		1 10	11 1	8 7	22 0	2 0 "	15 5 April
1915	.	2 7	10 6	9 2	21 8	2 5 "	15 4 "
1916		2 9	12 7	8 10	22 7	2 8 "	14 6 August
1917	.	2 10	12 7	9 6	22 10	3 7 April, Sept	14 7 February
1918		2 5	11 7	10 0	21 10	3 4 September	14 10 March

STATEMENT P.

Moyapur.

Datum, Kidderpur Old Dock Sill.

Year	Lowest low-water Ft	In	Highest low-water Ft	In	Lowest high-water Ft	In	Highest high-water Ft	In	Least range Ft	In		Greatest range Ft	In	
1875	2	0	10	3	9	6	21	0	1	9	September	15	11	April
1876	2	9	9	5	8	11	21	4	3	3	March	15	11	August
1877	1	2	8	9	9	0	21	3	3	10	"	16	10	"
1878	1	2	9	6	9	6	21	5	4	5	"	17	8	"
1879	2	0	10	0	9	4	21	9	3	10	"	16	0	May
1880	2	0	9	2	9	6	21	0	3	6	"	15	7	March.
1881	2	0	9	0	9	0	21	1	4	4	September	16	1	July
1882	1	5	8	1	10	0	21	1	4	2	March	16	3	Aug, Sept.
1883	1	7	8	0	9	6	21	0	5	7	February	16	0	Mar, Aug. Sept
1884	2	2	8	2	10	1	20	5	5	4	May	15	11	"
1885	2	0	9	8	9	8	21	6	4	6	September	16	5	August
1886	1	6	9	11	10	9	21	10	4	4	"	16	9	"
1887	1	10	9	7	9	6	21	8	5	3	March	10	9	April
1888	1	7	9	10	10	4	21	7	4	2	September	16	10	"
1889	1	6	10	10	9	11	20	11	3	8	"	16	2	May, June
1890	2	6	10	0	9	6	22	1	3	11	October	16	3	September.
1891	1	6	8	11	9	5	21	4	4	4	April	16	3	April
1892	1	2	8	7	9	8	21	5	5	0	March	17	7	March
1893	1	10	9	6	8	11	22	0	3	11	September	16	7	April
1894	2	0	10	6	9	0	22	1	3	4	Sept, Oct	16	3	August.
1895	1	5	8	8	8	0	21	4	1	7	March	16	10	"
1896	1	3	9	4	9	2	20	4	4	2	"	16	8	October.
1897	1	9	9	4	9	0	20	5	4	10	Sep, Oct.	16	8	April
1898	2	0	9	5	9	6	20	10	3	11	" "	15	11	July
1899	1	4	9	3	9	10	21	6	4	4	April	16	8	August
1900	1	10	8	10	9	11	21	4	4	6	"	16	10	"
1901	1	3	9	0	10	0	22	0 Cyclone	5	10	March	17	0	April
												20	0	Nov. Cyclone
1902	1	11	8	5	9	11	20	4	5	0	March	16	6	July
1903	1	1	8	11	9	11	20	10	5	[illegible]	September	17	1	"
1904	1	2	8	11	9	11	22	1	4	6	May	17	10	August
1905	1	0	8	11	10	3	21	8	5	3	April	17	6	April
1906	1	1	9	5	9	8	21	0	4	11	October	17	5	May
1907	1	0	8	5	9	11	21	2	5	1	March	17	8	June
1908	1	1	8	11	9	6	21	2	3	7	May	17	8	August
1909	1	1	9	6	9	11	21	4	4	3	March	16	10	March
1910	1	7	9	1	10	0	22	2	4	8	October	17	4	September
1911	1	7	9	2	9	0	21	10	3	5	March	16	11	August
1912	1	0	9	2	8	11	20	11	4	1	Sept, Oct	17	5	September.
1913	1	5	8	8	9	4	21	0	3	10	March	17	0	"
1914	0	11	9	5	8	11	21	0	4	7	September	17	0	April
1915	1	8	8	11	9	3	20	5	3	6	October	16	10	"
1916	2	0	9	2	9	3	21	0	3	2	April	17	0	August
1917	1	11	9	11	9	9	21	6	4	1	October	16	10	September
1918	1	6	8	11	0	3	20	10	3	11	April	16	2	March.

STATEMENT Q.

Hooghly Point.

Datum, Kidderpur Old Dock Sill.

Year	Lowest low-water Ft	In	Highest low-water Ft	In	Lowest high-water Ft	In	Highest high-water Ft	In	Least range Ft	In		Greatest range Ft	In	
1875 ...	0	9	8	8	9	9	20	11	3	6	September	18	1	April
1876 ...	1	0	8	3	8	10	21	0	3	1	March	19	0	August
1877 ...	0	3	7	9	9	3	21	3	3	7	"	18	8	"
1878 ...	0	0	8	3	10	0	21	0	4	4	"	19	5	"
1879 ...	0	4	8	6	9	10	21	5	4	4	"	18	2	April
1880 ...	0	9	8	1	10	0	21	0	3	11	August	18	3	August
1881 ...	0	6	7	9	9	5	21	0	4	8	September	19	9	"
1882 ...	0	0	7	5	10	4	21	0	4	5	March	19	7	"
1883 ...	0	0	7	0	10	0	20	8	6	2	March, May	18	10	"
1884 ..	0	1	6	10	10	1	20	1	5	11	May	18	5	September
1885 ...	0	5	7	7	9	11	21	1	5	1	September	18	10	August
1886 ...	0	1	7	6	10	5	21	1	4	7	April	19	4	"
1887 ...	0	1	Cyclone 7	9 12·1	10	6	21	1	5	10	May	19	3	September
1888 ..	0	1	7	6	10	3	20	6	5	1	September	19	3	April
1889 ...	0	2	8	8	9	9	20	2	3	10	October	18	3	"
1890 ...	0	0	8	2	9	5	21	2	4	5	March, Apl	19	4	August
1891 ...	0	1	7	5	9	5	20	8	4	5	April	19	4	"
1892 ...	0	1	8	4	9	11	21	3	4	3	September	19	3	March
1893 ...	0	2	8	2	9	1	23	0	3	10	"	18	5	April
1894 ...	0	8	8	10	9	1	Cyclone 21	2	3	5	"	19	2	September
1895 ...	0	2	7	6	8	0	20	11	1	8	March	19	2	August
1896 ...	0	1	7	10	9	7	20	1	4	1	"	18	7	September
1897 ...	0	1	8	4	9	9	20	1	4	0	September	18	6	April
1898 ..	0	2	8	7	9	10	20	2	3	9	"	19	1	September
1899 ...	0	4	8	0	9	10	20	8	4	5	April	18	8	August
1900 ..	0	1	8	0	10	2	20	10	4	10	"	18	10	September
1901 ...	0	1	8	1	10	4	23	4	6	0	March	18	5	Apl, Sept
1902 ...	0	1	7	3	10	3	Cyclone 20	1	5	3	"	18	3	August
1903 ...	0	0	8	2	10	2	20	6	5	0	September	19	3	Aug, Sept
1904 ...	-0	7	8	0	10	1	21	11	4	10	May	20	3	August
1905 ...	-0	6	7	11	11	1	21	5	5	10	April	20	1	September
1906 ...	-0	6	8	7	10	1	21	1	5	6	October	19	1	"
1907 ...	-0	2	7	11	10	0	21	0	5	0	March, Oct	19	11	June, Aug
1908 ...	0	1	8	0	9	7	21	6	3	6	May	19	4	August.
1909 ...	-0	3	7	10	10	2	21	5	4	2	March	20	1	September
1910 ...	-0	4	8	5	10	1	20	7	4	2	September	19	4	April
1911 ...	-0	1	8	0	9	4	21	1	4	2	"	18	9	September
1912 ...	-0	3	8	6	9	7	20	5	3	6	April	19	8	"
1913 ...	-0	4	7	4	9	6	20	11	3	8	March	19	7	"
1914 ...	-0	8	8	8	9	4	20	6	3	7	September	19	0	"
1915 ...	0	0	8	2	9	10	20	1	4	2	"	18	7	April
1916 ...	0	6	8	6	9	2	20	9	3	3	April	19	3	August
1917 ...	0	1	8	9	9	10	21	1	3	11	October	19	1	"
1918 ...	0	0	7	11	10	8	20	4	3	11	April	18	1	September

STATEMENT R.

Balari.

Datum 10 inches below Kidderpur Old Dock Sill.

Year.	Lowest low-water	Highest low-water	Lowest high-water	Highest high-water	Least range	Greatest range
	Ft In	Ft. In	Ft In	Ft In	Ft In	Ft. In
1875 ...	...	...	..	..	...	...
1876 ...	2 1	...	10 3	...		...
1877 ...	.	...	...	..	...	...
1878 ..	...	..	...	...	...	...
1879 ...	1 0	9 0	9 11	21 7	3 4 September	18 6 April
1880 ...	1 1	8 2	10 9	20 11	4 0 August	18 5 July
1881 ..	1 0	7 8	9 8	21 2	4 6 April	19 5 August
1882	0 7	7 10	10 1	21 7	3 11 March	19 7 ,,
1883 .	0 5	7 9	10 2	21 0	5 9 ,,	18 10 ,
1884 .	0 10	7 5	10 8	20 5	5 6 ,	18 5 ,,
1885 ..	1 0	7 9	10 0	21 3	5 0	19 0 ,,
1886 ...	0 11	7 11	10 10	21 3	4 9 ,,	19 0 ,,
1887 ...	0 6	12 6	11 0	22 5	5 6 April	19 1 September
1888 ...	0 5	8 0	10 8	20 7	4 6 September	19 7 April
1889 ...	0 10	9 1	10 3	20 1	3 6 October	18 10 ,,
1890 ...	1 2	8 11	10 0	21 7	3 1 ,	19 5 August
1891 ...	0 4	7 10	9 8	21 1	4 3 September	19 3 ,,
1892	0 3	8 6	10 0	22 2	3 9 ,,	20 3 ,,
1893 .	0 8	8 7	9 2	20 7	3 2 August	18 10 April
1894 ..	0 10	9 1	9 5	21 5	3 5 March	19 0 August
1895 ...	0 6	8 4	9 8	21 7	3 0 ,,	19 3 ,,
1896 ...	0 8	8 6	9 11	20 6	4 2 ,,	18 8 September
1897 ..	0 11	9 0	9 7	20 8	3 4 August	18 9 April
1898 ..	0 0	8 11	9 7	20 10	3 3 September	18 1 August.
1899 .	0 11	8 8	9 11	21 4	4 2 April	18 9 ,,
1900 ...	0 8	9 0	10 1	21 7	4 1 ,,	19 6 September
1901 .	0 9	8 11	11 0	20 6	4 8 ,,	18 4 May , Sept
1902	1 0	7 11	11 0	20 6	4 10 October	18 0 July
1903	0 3	8 5	10 5	20 11	5 6 ,,	19 2 August
1904 .	0 1	8 1	10 1	21 10	4 4 May	20 0 ,,
1905 .	0 0	8 4	11 0	20 8	4 11 August	19 5 September
1906 ...	0 3	9 1	10 1	20 0	4 0 September	18 10 May
1907 ..	0 1	7 10	9 11	21 0	4 5 March	19 7 August
1908 .	0 3	7 11	9 8	21 1	3 11 October	19 10 September
1909 ...	0 1	8 3	10 2	20 11	3 6 ,,	19 11 October
1910 ...	0 0	8 5	10 5	20 10	3 9 September	19 5 May
1911	0 2	7 11	9 1	20 8	3 11 March	18 2 September
1912 ..	0 0	8 7	8 11	20 6	3 3 September	19 7 ,,
1913 ...	0 1	7 6	9 5	21 8	4 0 March, Oct	19 8 ,,
1914 ...	-0 3	8 11	9 0	20 8	3 1 September	18 10 ,,
1915	0 9	8 9	10 0	20 0	3 4 October	18 3 May
1916 ...	0 9	9 2	9 6	21 0	3 2 April	19 0 August.
1917 ...	0 3	8 0	9 6	21 5	4 3 March	19 3 September
1918 .	0 2	7 11	10 4	20 13	5 4 September	18 3 ,,

STATEMENT S.

Khijiri.

Datum 1'-5" below Kidderpur Old Dock Sill.

Year	Lowest low-water		Highest low-water		Lowest high-water.		Highest high-water		Least range			Greatest range		
	Ft	In	Ft	In	Ft	In.	Ft	In	Ft	In		Ft	In	
1875			9	2	9	11	20	11	2	8	September	18	10	April, July.
1876	0	9	8	11	9	8	20	9	3	1	,,	18	10	July
1877	0	8	8	0	9	2	21	3	2	5	March	19	3	June, Sept
1878	0	6	9	0	10	2	20	9	3	0	August	19	2	August
1879	0	9	9	9	10	7	21	3	3	0	September	18	4	April
1880	0	8	8	9	10	5	20	9	3	6	,,	18	1	August
1881	1	6	9	0	9	9	20	4	3	8	,,	18	6	,,
1882	0	1	8	9	11	3	21	0	4	1	October	19	3	,,
1883	0	10	8	7	10	7	20	4	4	11	September	18	9	September.
1884	0	8	8	1	10	11	20	0	4	9	March	18	5	,,
1885	0	5	8	1	9	10	20	10	3	11	,,	18	10	August.
1886	0	9	8	2	11	0	20	9	4	0	,,	18	5	September
1887	0	4	13	0	11	2	21	6	4	9	September	18	11	August
			Cyclone				Cyclone							
1888	0	4	8	8	10	11	20	0	3	11	,,	18	6	April
1889	0	5	9	9	10	3	20	2	2	11	October	18	1	,,
1890	0	7	9	1	10	0	21	2	2	8	,,	19	4	August
1891	0	2	8	8	10	2	20	8	3	5	September	18	5	April
1892	0	2	9	9	10	3	21	10	2	6	October	19	6	March
1893	0	5	9	10	10	0	21	8	2	11	September	17	11	August
1894	0	11	9	9	9	7	20	11	2	6	March	18	5	,,
1895	0	9	9	1	9	10	20	11	2	9	September	19	2	,,
1896	0	11	9	10	10	4	20	1	3	2	,,	18	6	March.
1897	1	3	9	10	10	4	20	1	2	10	,,	17	10	August
1898	1	7	9	5	10	4	20	0	2	10	,,	18	0	,,
1899	1	9	8	10	10	11	20	8	3	2	,,	18	8	,,
1900	1	9	9	8	11	0	21	10	3	9	,,	18	0	,,
1901	1	5	9	10	10	9	19	9	3	7	,,	18	4	,,
1902	0	11	8	0	10	2	19	10	4	9	,,	18	0	,,
1903	0	9	9	1	10	4	21	6	4	1	,,	19	6	
1904	0	7	7	9	10	10	21	11	4	1	April	20	3	
1905	-0	7	8	6	10	7	21	5	4	8	September	19	6	October
1906	-0	2	9	0	10	2	20	0	4	0	,,	18	7	September
1907	-0	11	8	0	10	5	20	11	3	5	October	19	11	August
1908	-0	4	8	10	10	1	21	0	3	1	,,	19	4	Aug., Sept
1909	-0	2	8	3	10	3	21	9	3	7	,,	18	10	October
1910	-1	1	8	2	9	9	20	2	3	6	March	18	8	May
1911	0	2	8	10	9	4	20	3	3	1	September	18	3	August
1912	-0	3	9	2	9	1	20	1	2	10	March	19	8	September
1913	-0	2	9	4	9	9	20	7	2	11	,,	19	5	August
1914	-0	3	9	8	9	5	20	6	2	11	September	18	8	,,
1915	-0	2	9	11	10	4	19	7	2	7	October	18	7	April
1916	0	9	..		10	0								
1917			Khijiri Semaphore was dismantled in June 1916											
1918														

STATEMENT T.

Kidderpur.

Datum Kidderpur Old Dock Sill.

Year.	Lowest low-water	Highest low-water	Lowest high-water	Highest high-water	Least range	Greatest range.
	Ft In	Ft. In	Ft In	Ft In.		
1806 ...	1 11	12 11	9 3	22 7		
1807 ..	2 0	13 0	9 5	22 6		
1808 ..	2 1	11 7	9 4	22 2		
1809 .	2 3	12 3	9 5	22 6		
1810 .	2 1	10 7	9 6	21 7		
1811 .	1 10	11 7	9 7	22 2		
1812 ...	1 10	11 4	9 7	22 0		
1813 ...	2 4	10 6	9 7	20 10		
1814 ...	2 6	11 6	9 1	21 6		
1815 .	1 10	11 10	9 7	22 6		
1816 .	2 0	10 1	9 6	21 8		
1817 ...	2 2	12 1	8 11	22 5		
1818 .	2 6	13 7	9 4	22 7		
1819	2 6	12 6	9 3	22 3		
1820 ...	2 0	12 7	8 10	22 6		
1821 ...	2 0	12 5	9 7	22 6		
1822	1 11	14 3	9 2	22 7		
1823 .	2 4	20 6*	8 6	22 7		
1824 ..	2 2	12 10	9 3	22 4		
1825 .	2 4	12 3	10 0	22 2		
1826	3 1	13 4	10 6	22 2		
1827 ...	2 7	11 6	9 6	22 0		
1828	2 3	11 6	9 5	22 1		

* Due to Dumodar flood

APPENDIX III.

REPORT OF THE SPECIAL SUB-COMMITTEE.

I. At the first meeting of the Committee appointed to examine and discuss the report on the Nadia rivers by Major F. C. Hirst, I A., Director of Surveys, Bengal, it was decided to subdivide Major Hirst's report into convenient branches for discussion by the General Committee.

II. Chapters 1—VII of the report dealing with the geological aspect of the problem were referred to Mr H H Hayden, C I.E., and his report has been submitted to each member of the General Committee.

III. The following questions were referred to the Special Sub-Committee for report to the General Committee —

(1) Survey

(2) Land levels.

(3) Hydraulic observations (observation and collection of accurate hydraulic data)—

(a) Tidal river levels.

(b) Direction and velocity of tidal streams.

(c) Discharges

(d) Percolation

(e) Composition of bed, shoals and sediments observed

(f) Surface slopes

(g) Limits of spill

(h) Effects of Ganges canals on spill channels

IV. The Special Sub-Committee was constituted as follows —

The Hon'ble Mr C J Stevenson Moore, C V O, I C S, *President*

Lt-Col Ryder, C I E., D S O, R E,

Mr C Addams-Williams, C I E,

Major F C Hirst, I A, Director of Surveys, Bengal,

Mr S C Williams, Vice-Chairman of the Commissioners for the Port of Calcutta,

Commander E A Constable, R N, Deputy Conservator of the Port of Calcutta,

to which at a subsequent date Mr James E Roy of Messrs MacNeill & Co was added

The Hon'ble Mr Cowley was requested to assist the deliberations of the Special Sub-Committee by placing at their disposal his personal knowledge of the Nadia rivers Major Hirst having reverted to military duty was unable to attend the meetings of the Special Sub-Committee

V The Special Sub-Committee held four meetings on the following dates —

19th May 1917

23rd July „

31st „ „

17th August „

and made two local inspections—

(i) of the Bhagirathi mouth on the 22nd of April 1917,

(ii) of the Hooghly River between Naihati and Howrah on the 19th August 1917

VI. The Special Sub-Committee's report is as follows —

In Chapter IX of his report Major Hirst deals with the question of interference by human agency with the regimé of the Nadia rivers

This chapter is partly historical, partly conjectural, and partly fact The main point which Major Hirst appears to wish to bring out is the number and nature of embankments now existing in the Murshidabad district which have been the cause of restricting the natural spill of the flood water from the Nadia rivers.

The Special Sub-Committee are convinced that this argument is one which requires careful investigation, and it was recognised that at the present time maps showing the limits of the spill areas of river in Bengal, except in a few observed localities, are not available.

It was resolved that the Government of Bengal should be requested to have spill area maps of all the rivers in Bengal prepared, as in the opinion of the Sub-Committee these maps are essentially necessary for the proper preparation by Railway Companies of railway projects and for their proper examination with reference to the waterways provided in the railway banks by the Irrigation Department.

The procedure at present observed for the examination of waterways in railway embankments was, in the opinion of the Special Sub-Committee, inadequate. It was consequently resolved that in all pending cases of embankments for either railways or roads, the Bengal Government should be approached with a view to the issue of orders that a representative of the Irrigation Department should be deputed to ascertain that the waterways as provided in any project approved by Government, for either a railway or a road, had been constructed in accordance with the orders of Government. It was thought that this matter could easily be arranged in collaboration with the Government Inspector of Railways, who has to inspect every railway line on completion before it is open to traffic

VII Chapter X of Major Hirst's report deals with the condition of the Hooghly River from the Mathabhanga-Bhagirathi junction to the Howrah Bridge He points out that this length of the river is under nobody's care,—it has not been declared under the Embankment Act of 1882, nor is it included within the limits of the Port Commissioners' charge. He points out that he has not been able to substantiate the charge of deterioration in this length of the river, but he has sought for obviously visible causes of deterioration He then proceeds to enumerate the obviously visible causes of deterioration and sums up as the result of enquiries as follows :—

(*a*) There is less water at low-tide over shoals than there was 20 years ago

(*b*) Shoals have increased in size

(*c*) Shoals occur now where none existed before.

(*d*) In a few cases original shoals have disappeared

(*e*) The courses for steamers are far more tortuous now than formerly.

To examine at first hand the conditions prevailing the Special Sub-Committee, together with Mr A R. Murray and Mr J. Campbell, made a river trip from Naihati to Howrah on the 19th August, and Mr Murray has kindly promised to lay a note on this chapter of Major Hirst's report before the Committee.

VIII. Chapter XI of Major Hirst's report deals with the effect of the Gangetic irrigation canals upon the Hooghly river. Major Hirst has tabulated some interesting figures of the computated maximum and minimum discharge of the Ganges in the neighbourhood of the Bhagirathi offtake, and he quotes Sir M. Nethersole's computation of the volume of water absorbed during low-water seasons by the Gangetic canals

He calculates that the fresh water-supply from the Ganges to the Hooghly has been reduced by about 10 per cent during those periods of the year in which the spill channels most need extra water, and therefore deterioration in the spill channels might be expected.

He states that on the whole it seems clear that the canals have affected the amount of water available for the Hooghly, but there is no certain evidence that less water passes down the Nadia rivers now than they received before the canals were opened

The Special Sub Committee after careful discussion of these views realised that it would be difficult to take any action in so far as completed projects for irrigation are in existence It was resolved that it was necessary that before schemes of irrigation or increase of supply to existing canals taking off from the Ganges were sanctioned, the effect of the reduction of supply in the discharge of the Ganges to the country below should be more carefully considered and more weight given to the other interests concerned than appears hitherto to have been the case. The Government of India should consult the Lower Provinces before large schemes of irrigation in the Upper Provinces involving a considerable reduction in the discharge of the Ganges are sanctioned

IX. Chapter XII of Major Hirst's report deals with the very important question of shoals in the Nadia rivers. Unfortunately Major Hirst has not given us any clear indication of the methods to be employed in dealing with these shoals He suggests, however, that the abnormality between bar heights and pool depths in the Bhagirathi has not received the attention it deserves, and unless it receives such attention the river will not be opened up permanently to any function that it is expected to perform.

The Special Sub-Committee are convinced that this question of observation of the shoals must in future be carefully and systematically carried out The length, breadth and shape of existing shoals should be observed and all alterations carefully noted.

The Special Sub-Committee, therefore, decided that a complete survey of the Bhagirathi river (in the first instance and subsequently of the Jalangi, Matabhanga and Bhairab) from the Ganges as far down as the mouth of the Mathabhanga was necessary, and that on this survey map the position of all shoals should be located.

X. Chapter XIV of Major Hirst's report deals with the very important question of discharge observations in the Nadia rivers.

He describes the action taken in 1914 and subsequently for the gauging of the Bhagirathi and its tributaries on the west and criticises the methods employed. The conclusions arrived at by him are that the discharge observations are not entirely reliable, and that the method of obtaining the discharges from the tributaries on the west is inaccurate as percolation water might be ascribed to the discharge of an intermediate

river which was not supplying any water. He also advises the abandonment of discharge observation in tidal areas, and finally, he suggests an arrangement of the observation stations increasing their number to 31.

Major Hirst, however, recommends that until such time as the whole question of collection of hydraulic data in connection with the Nadia rivers has been considered by this Committee, the existing arrangement regarding discharge observations should be continued.

The Special Sub-Committee have carefully considered Major Hirst's suggestions and have come to the conclusion that the discharge observations now being taken by the Public Works Department should be continued and the question of undertaking detailed tidal observations between Calcutta and Nadia should be considered by the Port Commissioners, and definite proposals submitted to the Committee for the same

The discharge observations by the Public Works Department are being continued and proposals have been submitted by the Port Commissioners for the Port of Calcutta for establishing tidal observation stations between Calcutta and Nadia

The proposals of the Port Commissioners have been circulated to the members of the Committee.

As regards the number of observation stations, the Special Sub-Committee have very carefully considered Major Hirst's proposals for increasing the number of discharge observation stations, and do not agree that their number requires to be increased so long as separate observation of the discharges of the Farucca channel, Banslai, Babla, Ajai and other affluents are also taken

This means that the Special Sub-Committee considered that discharge observations should be taken at the following stations —

(1) In the Farucca channel above the Bhagirathi intake
(2) In the Farucca channel below the Bhagirathi intake
(3) Geria in the Bhagirathi river
(4) Banslai River in the Banslai above its outfall into the Bhagirathi
(5) Berhampur in the Bhagirathi
(6) Jhumjhumkhali in the Bhagirathi
(7) Babla River in the Babla above its outfall
(8) Databati in the Bhagirathi.
(9) Ajai in the Ajai above its outfall into the Bhagirathi
(10) Katwa in the Bhagirathi
(11) Panditpur in the Jalangi river
(12) Satgachia in the Bhagirathi.
(13) Hanskhali in the Mathabhanga river

In the following statement the observation stations recommended by Major Hirst are detailed with the recommendations of the Special Sub-Committee in regard to their retention or otherwise —

	Major Hirst's proposed stations	Special Sub Committee's recommendations
1	Biswanathpur in the Bhagirathi.	This does not appear necessary if an observation station is fixed at Geria, a mile below the entrance
2	Farucca channel above the Bhagirathi offtake	This is retained, and in addition an observation station is proposed in the Farucca channel below the Bhagirathi offtake
3.	Above the Banslai entrance in the Bhagirathi	This does not appear necessary when there is an observation station at Geria
4	In the Banslai	Retained.
5.	In the Bhagirathi below the Banslai	This does not appear necessary when the station at Jangipur is retained
6	5-10 miles below Jangipur in the Bhagirathi	Ditto ditto
7.	Berhampur	Retained
8.	Jhumjhumkhali	Do
9	In the Bhagirathi above Babla mouth.	Does not appear necessary when the Jhumjhumkhali station is retained
10	In the Bhagirathi below Babla mouth.	Does not appear necessary when a station in the Babla itself as well as another at Databati below the Babla mouth are retained
11	In the Babla.	Retained
12	In the Bhagirathi above Ajai mouth	Does not appear necessary when the Databati station is retained.
13.	In the Bhagirathi below Ajai mouth.	Does not appear necessary when a station in the Ajai itself is retained and another at Katwa below the Ajai mouth.
14.	In the Ajai river	Retained
15.	In the Bhagirathi above Jalangi entrance.	Does not appear necessary when the Katwa station is retained

Major Hirst's proposed stations	Special Sub-Committee's recommendations
16. In the Bhagirathi below Jalangi entrance.	Does not appear necessary when a station is retained in the Jalanghi at Panditpur and another at Satgachia
17. In the Jalangi river.	Retained.
18 Hanskhali in the Mathabhanga	Do
19-30	These stations do not appear to be necessary for the purpose of ascertaining the fresh water-supply to the Hooghly. They would be useful for ascertaining the volume of water admitted into the delta of each river for purposes of land building, but would not be of practical assistance to forming ideas for the improvement of these rivers for navigation purposes. The stations which have been fixed upon will give all necessary information for the Bhagirathi river. Major Hirst in Chapter XX, paragraph 20, of his report recommends that the prospect of improvements should be for the present confined to the Bhagirathi alone
31 In the Hughli at Howrah	The Port Commissioners will take discharge observations, both here and at Garden Reach. It was not thought desirable to fix observation stations for taking the discharge of the Saraswati and the Khaira as the volume of water taken out of the Hooghly by these rivers can only be very small and then only during high floods in the river

Major Hirst's proposals for 31 observation stations appear to have been based upon the view that in taking these discharge observations the effect of percolation must be studied. The volume of percolation which finds its way into the river is greatest during the hot weather and in the monsoon is negligible

The object of these observations being to estimate the volume of fresh water-supply entering the Hughli *via* the Nadia rivers, and to compare the present supply with such records as are available of the supply in former years, and also to establish a record for comparison in the future, it does not seem essential that the volume of percolation water entering the river should be very accurately determined

For these reasons the Special Sub-Committee are of opinion that many of the observation stations proposed by Major Hirst are not necessary and are also of opinion that the statement of discharge observations as obtained from the proposed discharge observation stations will afford sufficient data to arrive approximately at the amount of percolation during the hot and cold weather months.

XI. In Chapter XV of his report Major Hirst deals at great length with the subject of dredging and bandalling, the methods employed, the objects aimed at, and the results achieved. He generally disapproves of the methods employed and makes certain suggestions for improvement thereon

The Special Sub-Committee very carefully considered Major Hirst's report and are of opinion—

(*i*) that no very definite results have been obtained from the present system of dredging the Bhagirathi at its offtake and bandalling shoals lower down,

(*ii*) the dredging to some extent provides for a small increase in the supply of water for domestic and sanitary purposes, but is of no benefit to the permanent regime of the river,

(*iii*) the bandalling works maintain navigable channels between places situated on the banks of the river within such reaches where there are no high shoals. The results are of a purely temporary nature.

In view of Major Hirst's remarks on the methods employed in dredging and bandalling the Special Sub-Committee considered the question of issuing rules as to the methods which should be employed and the objects to be attained by such works, but came to the conclusion that it was not possible for them to formulate such rules. This question must be left for the decision of the local experts who had been connected with dredging and bandalling works for many years

XII. In Chapter XVI of his report Major Hirst deals with sediment observations. He points out that no regular observations of the amount of sediment carried in suspension by these rivers have been carried out; he argues that there are several highly important reasons why such observations should be made. He describes a simple method for taking sediment observations and suggests that it will be necessary to take sediment observations at three depths—surface, mid-depth and one foot above bottom. In addition the material of the bottom should be ascertained by tallowing the end of the lead. He then proceeds to lay down the procedure to be followed when taking such experiments.

The Special Sub-Committee after a careful consideration of these remarks decided that it was necessary that such sediment observations should be taken

It was therefore resolved that silt observations should be taken daily at Katwa, Swarupganj and Hanskhali by the Public Works Department and at the Howrah Bridge by the Port Commissioners.

The Public Works Department and the Port Commissioners should collaborate so that the observations may be taken in the same manner at all stations.

As regards observation of the composition of bed, it was resolved to await the report which Mr. Hayden had been asked to submit

XIII In Chapter XX of his report Major Hirst summarises his general proposals

(i) *Levels.*—This question was carefully considered by the Special Sub-Committee, it was pointed out that no recent maps of the area covered by the Nadia rivers were available, and the paucity of levels of precision was a decided obstacle in the way of scientific enquiry into the present conditions prevailing in this area with a view to river observations, ultimate river improvement, drainage and land raising operations

The Subject "Survey" may be divided into the following subheads—

(*a*) levelling,

(*b*) traversing or triangulation necessary as a basis for detailed maps,

(*c*) preparation of detailed maps

With reference to levelling operations it was essential that all levels quoted in connection with the Hooghly and the Nadia rivers should be reduced to a common datum, *i.e.*, the latest Great Trigonometrical Survey values relative to mean sea-level.

The question of running new lines of levels of precision as suggested by Major Hirst in paragraph 1, Chapter XX of his report, was referred to the Surveyor-General in India for report as to what levelling of precision he could undertake to carry out and which lines he would recommend

In submitting this question to the Superintendent, Trigonometrical Survey, the lines of levels of precision suggested by Major Hirst were detailed, and it was pointed out that levels of precision had already been run along the Eastern Bengal Railway embankment from Barrackpur to the Ganges, and that the Special Sub-Committee were of opinion that the Public Works Department could run the special lines of levels to the selected discharge observation stations

The following lines, viz, along the railway on the right bank of the Bhagirathi and the river, continuation of the lines of levels to the Ganges at Rajmahal, might be considered as one

The line along the railway on the left bank of the Bhagirathi would be so close to the line on the right bank that it might be preferable to run a line along the left bank of the river, then from Jiaganj to Azimganj, and then along the railway to Barharwa

The line along the right or left bank of the Jalangi might be run by the Public Works Department, if, as suggested by that Department, a line of levels of precision was run from Berhampur to Chuadanga on the Eastern Bengal Railway

The meaning of the term "Cone area" referred to by Major Hirst in his report had not been clearly defined

The Superintendent, Trigonometrical Survey, in his reply to this reference expressed his inability from a perusal of Major Hirst's report to formulate recommendations as to the lines of levels of precision to be undertaken, he pointed out that the necessity of taking such lines of levels of precision as had been suggested did not comply with the conditions required by the Survey of India for the taking of levels of precision, but he was of opinion that the following lines of levelling might legitimately be undertaken by the Trigonometrial Survey of India —

(*a*) Ranaghat *viâ* Berhampur, Murshidabad, Jiaganj to Lalgolaghat.

(*b*) Jiaganj to Azimganj, thence by road to Rajmahal, and from Rajmahal to Tinpahar to connect with line 74

(*c*) Berhampur *viâ* Meherpur to join line 77 at Chuadanga.

(*d*) The crossing of the Ganges at Saraghât to be revised now that the Harding Bridge is available, and a line run from some point on line 77 through Rampur-Boalia to Godagari and thence to Manihari opposite Sahebganj

A line from Ranaghât to Jessore and thence *viâ* Jhenida to Chuadanga might also be undertaken He, however, pointed out that there is no prospect of these lines of levels of precision being taken up for a long time to come, as, on account of the war, the number of levellers available for work in the field season is now reduced to a minimum and programmes now are lying ahead for lines of levels aggregating 900 miles the only thing that might be done at once is to get bench-marks ready and to wait until normal conditions return.

These notes were discussed at the second meeting of the Special Sub-Committee and it was resolved that the lines of levelling of precision enumerated (*a*), (*b*), (*c*) and (*d*) in the foregoing paragraph were urgently required, and that the Government of Bengal should be requested to address the Department of Revenue and Agriculture, Government of India, to arrange for them to be undertaken by the Survey of India as soon as possible.

Land levels.—A map showing the lines of levelling in the Nadia and Murshidabad districts run by the Public Works Department in connection with sanitary drainage projects, was placed before the Special Sub-Committee and it was resolved that these lines of levels should be continued and completed in the districts of Nadia and Murshidabad The question of the extension of these levelling operation into the Burdwan district was also discussed, and it was resolved that they should be so extended as far as the Burdwan-Mangalkot road on the west and the old line of the Damodar river on the south

In connection with the subject of the datum to which all levels should be referred, it was decided to refer to the Survey of India the question of the correct value of the Kidderpur Dock Sill reduced to mean sea-level

The explanation supplied by the Survey of India is as follows —

The earlier levels of the Great Trigonometrical Survey all depended on the determination of mean sea-level at Karachi The connection of Kidderpur with Karachi was completed in 1865 and gave the height of the Dock Sill as 6 25 feet below mean sea-level at Karachi

Between 1881 and 1883 the Tidal Observatory which had been established at False Point in 1880 was connected with Kidderpur by portions of several lines of levels The resulting height of the Dock Sill was 7 986 below mean sea-level at False Point, showing that in the long line from Calcutta to Karachi an error of 1 73 feet had accumulated.

When the whole of the lines of levels were adjusted, which was done between 1905 and 1910, small corrections were made to reconcile discordance between the different lines and to introduce improved values of mean sea-level as determined by long series of observations at the several tidal observatories. After applying these corrections the finally adopted Kidderpur Dock Sill was 7 759 feet below mean sea-level The mean water-level at Kidderpur is 3 170 feet above mean sea-level

(*ii*) *Traversing or triangulation necessary as a basis for detailed maps*—It was pointed out that the Survey of India are running traverses in connection with their 1" survey, and as this survey would include the area covered by the Nadia rivers, it was decided to ask the Survey of India to bear in mind when running these traverses that a larger scale survey of the rivers and the country in their immediate neighbourhood would be required and to ask them to fix, if possible, a sufficient number of traverse points within this area.

These points supplemented by traverses which could be carried out by the Director of Surveys, Bengal, along the protective bunds would suffice for any surveys required.

It was resolved—

(*a*) to enquire from the Director of Land Records when the cadastral survey of the area bordering on the Bhagirathi in the districts of Nadia and Murshidabad will be taken up with a view to ascertaining when the 16" = 1 mile cadastral maps of the river and its banks would be available ,

(*b*) to request the Government of Bengal to collaborate with the Survey of India with a view to ensure that the traverse marks erected by the latter should be used, subject to any additional marks required by the cadastral survey, in the preparation of further surveys These marks should be of such a permanent nature as will always be available for future reference, specially for the preparation and relaying of the large scale detailed river surveys which will be required along the banks of these rivers

Maps of this nature are required by the Committee, as soon as possible, and it was therefore resolved to request the Government of Bengal (in the Survey Department) to take up the question of collaboration with the Department of Revenue and Agriculture of the Government of India

The question of the necessity of further surveys was again discussed at the third meeting of the Special Sub-Committee, and it was resolved that it was desirable that a survey of the Ganges be made from a point about 5 miles above the offtake of the Farucca channel down to a point below the mouth of the Bhagirathi in the neighbourhood of Kalyanpur.

The width of the surveys should extend as far as the known limits of the variations of the Ganges stream within recent years

An enquiry should be made from the Directer of Land Records to ascertain if the diara survey in the district of Malda will be of any help in this matter

(*iii*) *Preparation of detailed maps.*—It was pointed out that the Survey of India was carrying out a survey of this area on the 1" = 1 mile scale in the ordinary course of their topographical programme This work will be completed in about three years. This map, when complete, will supply a good general map of the whole area under investigation, but a larger scale 4" or 6"=1 mile map would be necessary of the rivers and their immediate neighbourhood, based on the traverse mentioned in the forgoing paragraph.

XIV The remaining proposals of Major Hirst within the terms of reference to the Special Sub-Committee have been dealt with in the foregoing paragraphs. Such proposals as have not been dealt with have been deemed to be more fit for discussion by the General Committee The following points have, however, been discussed and deserve special attention —

(*a*) *Surface slopes*—The question of accurate determination of the surface slopes of the river water was discussed. It was realised that the difficulty was a very real one, and it was resolved that masonry chambers similar to those employed on the Punjab canals should be constructed experimentally at selected places and gauges fixed within these chambers so that the water-level should not be disturbed by wind or wave action.

Experiments with other types of enclosed chambers, such as chambers made of bamboo mats, might also be experimented with.

(*b*) *Current metres*—The question of observing discharges with the aid of current metres was discussed. It was pointed out that the current metres at present used were not reliable, and the difficulty was to obtain a current metre which was reliable. It was resolved that the Government of Bengal be requested to address the Government of Madras with a view to obtaining a descriptive report of the methods employed in gauging the Cauvery river.

It was also decided that the Port Commissioners should enquire from the Port Commissioners of Rangoon what results have been obtained with the Ritchie-Haskell current metre, and whether the results are in their opinion reliable

It was also decided to request the Bengal Government to enquire from the American Society of Engineers what methods were employed in gauging the discharges of the Mississippi.

It was also decided that the Bengal Government should be requested to address the Chief Engineer in Sind with regard to the determination of the discharges of the Indus river

C J STEVENSON-MOORE,

President

The 5th December 1917.

APPENDIX IV.

Note by Mr. Addams-Williams on the deltaic rivers.

In paragraph 34 of Chapter I of Mr Reaks' report on the Nadia rivers (Appendix II) the probable sequence of events with regard to the leading changes in the courses of the main rivers in Bengal is given, but nothing is said regarding the probable conditions before the Ganges changed its course to the east in the 16th century except in paragraph 11 of Chapter II, where it is stated that the existence of the Swatch appears to show that "no main branch of the Ganges can ever have detouched for any length of time through the middle region of the delta." In the footnote to page 17 it is stated that the Kosi originally combined with the Mahananda and flowed through the Baral-Atrai rivers into the Brahmaputra

Is it not reasonable to suppose that before the Ganges changed its course, the Kosi, Mahananda, Tista and other rivers issuing from the north found a common outlet south-eastwards in the direction of Goalundo and at or near that place combined with the Brahmaputra (possibly before it broke through the Himalayas and was therefore a smaller stream than now) and passed on to the sea either through the present Meghna (improbable) or somewhat further west near Madaripur through the old Bhubaneswar to the south-east of Faridpur, which is stated to be the earliest known course of the Brahmaputra? And is it not probable that the Ganges broke through into the combined Kosi and Mahananda following the Baral-Atrai course, and thence by more or less the same route to the sea *via* Faridpur and Madaripur, throwing off a large spill channel, the Dhaleswari-Buriganga? If these conjectures are correct there would be an intermediate portion of the delta, triangular in shape, lying between the Mahananda-Brahmaputra series on the north and east and the Ganges series on the extreme west, which may be termed the central delta

A glance at the map will show that from the Hooghly up to the Marjata estuary the exposed delta face is as advanced as any, in fact, a little more so this portion is traversed by rivers which at one time must have been very active delta-builders as evidenced by their great tortuosity and old loops Among them are the Ichhamati, probably an old branch spill of the Bhairab, the Kodla, an old spill mouth of the Ichhamati, the Betna, an old spill mouth of the Bhairab, the Kobadak, also a spill of the Bhairab, the Harihar and Bhudder, both spills of the Kobadak, and the Mukteswari, probably once a spill of the Bhairab above Jessore All these rivers were therefore served by one parent stream, the Bhairab, and it is therefore clear that this river must have been a very important mouth of the main Ganges which running south-eastwards to Khulna passed almost exactly central between the other two main systems of the east and west already mentioned These old delta-builders can at the present day be traced down to at least the latitude of Calcutta maintaining the true characteristics of fresh water spill channels down to this line it is quite probable that they all extended still further south, but owing to the change in the course of the Ganges, which reduced and eventually cut off the supply of silt-laden water, the lower reaches have now been "covered up" by tidal action from the south which has laid down a stratum of alluvium with a general slope from south to north as explained in paragraph 20 of Chapter II of Appendix II

At the present day the best example of this action of the tides will be found to the west of Khulna where the tides are busily raising the land by spill and are rapidly cutting off the old loops, so that in the case of the Bhudder and Kobadak an entirely new system of the rivers is in process of formation causing the older streams to be cut up into independent sections which by forming tidal meeting grounds will lead to the extinction of the old loops in the near future

It appears clear then that the Bhairab has constituted the central delta-builder and was a very important mouth of the Ganges issuing from the very head of the delta, and it likewise follows that the Bhairab in the days of its greatest activity issued not from the *right* bank of the Ganges, but from the *left* bank and was in existence for many years before the Ganges turned eastward it appears also probable that this change in the course of the Ganges was due to the Bhairab bursting its left bank into the Mahananda which gave the Ganges a lead on its new journey and thus the central delta-builders were thrown on to the right bank of the present river such an avulsion is in the nature of a "cut off" and the effect probably was that the level of the Ganges above the avulsion was lowered and that of the Mahananda raised, so that a bar must have formed at the head of the old river, now called the Bhagirathi, and also probably at the new head of the Bhairab and the supply to both rivers much reduced it is therefore probable that as the old southerly channel of the Ganges was robbed of water and the Mahananda reinforced, the difference in water levels between the old and new courses was so great as to cause the Jalangi to open in a south-westerly direction to be followed later by the Matabhanga thus the general south-easterly flow of the rivers in the central delta was gradually turned south-westwards, the whole of the alterations being the outcome of the change in the course of the Ganges

We have at the present day very similar conditions below Faridpur, where about 100 years ago the combined Ganges and Brahmaputra changed from the Madaripur course to the present one through the Kirttinasa and thus into the Meghna estuary · yet the old course *via* Madaripur, called the Arial Khan, is kept active by spill channels, the principal

of which are the various Mainakata offtakes on the 16th October 1915 all these offtakes were nearly closed by bars which caused the level in the river below to fall, creating sufficient fall through a small khal (the Kutubpur), so that by the 26th of November this khal had opened and carried a large volume of water into the Mainakata and on that date was actually used by one of the steamers · since then this khal has widened into a moderately large river.

The Nabaganga was probably a left bank spill of the Bhairab which has now severed connection and with its second mouth, the Chitra, raised the delta in the central part of the Jessore district further to the north is the Kumar which may likewise have been a left bank spill channel of the Bhairab high up · but there appears to be a still older river in this vicinity, viz., the Barassi, which can be traced in three places more or less close to the Kumar the Bhabanipur khal to the north-west of Jhenida is called the Barassi to the north-east of Magura another short length is called the Barassi whereas the same name is also given to the river on the west of the Madhumati near Bhushna the Kumar appears to be a younger river than the Barassi as it is at the present day a continuous river flowing on much the same alignment as the Barassi The lower reaches of the Barassi have now been absorbed in the Madhumati, but it is clear from Rennell's Memoirs and maps that this old river discharged into the Haringhata estuary and possibly the Bureswar near Pirojpur is a portion of the old river, the spelling having been mutilated It appears also that the Padma was in existence previous to the Ganges going east we find an old river-bed to the north-west of Faridpur called the Mara Padma, now a small khal, which tends to confirm the existence of such a river the Padma was therefore in all probability the most northern spill channel of the Ganges, and to its north and close by the Mahananda series of rivers flowed more or less parallel, but their courses may have been at some previous date in a more southerly direction and may be now covered up by the more recent delta.

The contentions put forward here appear to indicate that all the present delta building spill rivers, except the Jalangi, Matabhanga and Gerai, date back to the time when the Ganges flowed past Calcutta, and whichever rivers issued from the Ganges did so from the left and not from the right bank , otherwise it seems impossible to explain the fact that the central delta sea face is so advanced Also the Bhairab must have been the main central delta-builder 400 years ago it is stated that Jessore was on the sea face this is not probable, but it indicates that the Bhairab was a large river at that time, i e , about the time the Ganges went eastwards, and it is possible to understand that much of the country near Jessore then presented the aspect of a vast sea due to the low-lying lands, now called bils, which must have overflowed during the annual inundation Much of this low land in 1876 lay only from 2 to 4 feet above old mean sea-level, and it is probable that the tides from the south have always spilled over it as they do so at the present day when the land is probably higher than it has ever been since the Ganges became an active delta-builder in these parts

The existence of the Swatch is not antagonistic to the contention that there was a large river running through the central delta for many years It is probable that the Bhairab carried at least as much water as the western Ganges the latter distributed its supply of sediment, so far as we know, over a comparatively small portion of the sea face The Saraswati and Adi Ganga (Tolly's Nala) so far as can be judged at the present day were not very large rivers and the third mouth, the Jabuna, which mingled its water with the Bhairab through the Ichhamati was also not a large river and its course to the sea below the confluence would indicate approximately the division between the western Ganges built delta and that built by the offshoots of the Bhairab moreover, the Bidyadhari was almost certainly a mouth of the Jabuna as its old course can still be traced by that name almost up to Basirhat, and therefore this river distributed a portion of the silt supply of the Jabuna and Ichhamati south-westwards along the Matla estuary We know that the Bhairab used to discharge into the Haringhata estuary and excluding any portion of the delta north of the Bhairab, the area built up south of the river exceeds that which can be placed to the credit of the Western Ganges it is therefore not at all improbable that the Bhairab was the more important river of the two, and that when active was actually filling the bed of the Bay and would have filled up the Swatch had not the Ganges changed its course and so reduced the head water-supply the result of this change as we have seen was to change the direction of drainage south-westwards at the head of the delta so that the silt supply was entirely conducted through the present Hooghly and was also reinforced by that brought in by the western tributaries the 100 fathom contour of the Swatch reaches to within 20 miles of the sea face yet 4½ miles closer to the coast the depth is reduced to only 10 fathoms this sudden rise may possibly be the edge of the advancing delta of the Bhairab offshoots

If the contentions regarding the Bhairab are correct it may be asked why the under-sea delta has not advanced at the same rate throughout since my explanation of the formation of the Swatch is that it consists of a small portion of the sea-bed as yet unfilled by sediment, there being an under-sea delta plinth advancing towards it from both east and west, the two not having yet met It appears likely that the formation of the Ganges delta forced all the southerly running rivers which issued from the Himalayas north of the present Padma south-eastwards, so that they concentrated their delta building functions in the eastern portion of the Bay and in the same way there appears to have been a similar concentration on the western side through the Western Ganges, so that both plinths advanced across the sea face to meet one another the activities of the Bhairab system being distributed over a much larger area and longer sea coast the formation of the under-sea plinth was retarded in the central portion . in the last

400 years the silt supply through the central delta has been almost cut off and has been concentrated in building up the eastern and western plinths, the activity being more marked in the case of the eastern plinth which is supplied by a comparatively large proportion of the silt bearing rivers and 100 years ago was largely augmented by the change in the course of the Brahmaputra westwards to Goalundo from the Sylhet jhils If therefore the points discussed here are substantially correct it is clear that the various changes which have taken place in the delta can be explained as being the outcome of natural causes due to ordinary deltaic action and are not necessarily due to tectonic forces.

One more point may be mentioned the mouths of the Kosi and Mahananda are said to have moved westwards, the Kosi having at one time flowed into the Mahananda and close to Purnea these movements may likewise have been brought about by the change in the course of the Ganges this river may have caused heading back in the northern rivers and on account of the level of the Ganges having fallen above the point of avulsion may have drawn both rivers to points further upstream a good example of this nature is the case of the Dhaleswari which, since the Brahmaputra has flowed past Goalundo, has moved its offtakes a good many miles up the Brahmaputra and appears to be still doing so, last year's new mouth being above that of the previous year

B S Press—21-7-1919—4578J—200—R F & others

Published at the Bengal Secretariat Book Depot, Writers' Buildings, Calcutta.

OFFICIAL AGENTS.

In India—

Messrs Thacker, Spink & Co, Calcutta and Simla
Messrs Newman & Co, Calcutta
Messrs Higginbotham & Co, Madras
Messrs Thacker & Co, Ld, Bombay
Messrs A J Combridge & Co, Bombay
The Superintendent, American Baptist Mission Press, Rangoon
Mrs Radhabai Atmaram Sagoon, Bombay
Messrs R Cambray & Co, Calcutta
Rai Sahib M Gulab Singh & Sons, Proprietors of the Mufid-i-am Press, Lahore, Punjab
Messrs Thompson & Co, Madras
Messrs S Murthy & Co, Madras
Messrs Gopal Narayan & Co, Bombay
Messrs. B Banerjee & Co, 25 Cornwallis Street, Calcutta
Messrs S K Lahiri & Co, Printers and Booksellers, College Street Calcutta
Messrs V Kalyanarama Iyer & Co, Booksellers, etc, Madras
Messrs D B Taraporevala & Sons, Booksellers, Bombay
Messrs G A Nateshan & Co, Madras
The Indian School Supply Depôt, 309, Bowbazar, Calcutta
Mr Ramnath Sunder, Bombay
Messrs A M and J Ferguson, Ceylon
Messrs Temple & Co, Madras
Babu S C Talukdar, Proprietor, Students & Co, Cooch Behar
Messrs Ramchandra Govind and Son, Booksellers and Publishers, Kalbadevi, Bombay
Messrs Butterworth & Co (India), Ld, Calcutta
The Weldon Library, 18 5, Chowringhee Road, Calcutta
Rai M C Sarkar Bahadur & Sons, 90-2A, Harrison Road, Calcutta
The Proprietor of the Newal Kishore Press, Lucknow
The Standard Literature Company, Ld, 13-1, Old Court House Street, Calcutta
Mr G N Haider, Calcutta
Messrs Vas & Co, Madura
Messrs A H Wheeler & Co, Allahabad, Calcutta and Bombay
M R Ry E M Gopalakrishna Kone, Madura
Messrs Rama Krishna & Sons Anarkali Street Lahore
The Manager, "Hitavada", Nagpur
The Young Men's Christian Association Press, Calcutta
Messrs Lal Chand & Sons, 76, Lower Circular Road, Calcutta
The Standard Bookstall, Karachi
Mr Mangaldas Harkisandas, Surat

In Great Britain—

Messrs A Constable & Co, 10, Orange Street, Leicester Square, London, W C
Messrs Grindlay & Co, 54, Parliament Street, London, S W
Messrs Kegan, Paul, Trench, Trubner & Co, 68-74, Carter Lane, London E C, Oriental Department, 25, Museum Street, London, W C
Mr B Quaritch, 11, Grafton Street, New Bond Street, London, W
Messrs W Thacker & Co, 2, Creed Lane, Ludgate Hill, London, E C
Messrs P S King & Son, 2 & 4, Great Smith Street, Westminster, London, S W
Messrs H S King & Co, 65, Cornhill, London, E C
Mr B H Blackwell, 50-51, Broad Street, Oxford
Messrs Deighton, Bell & Co, Ld., Trinity Street, Cambridge
Messrs Luzac & Co, 46, Great Russell Street, London, W C
Messrs Oliver & Boyd, Tweeddale Court, Edinburgh
Messrs E Ponsonby, Ld, 116, Grafton Street, Dublin
Mr T Fisher Unwin, Ld, 1, Adelphi Terrace, London, W C
Messrs William Wesley and Son, 28, Essex Street, Strand, London

On the Continent—

Mr Ernest Leroux, Rue Bonaparte, Paris, France
Mr Martinus Nijhoff, The Hague, Holland.